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PHYSICS 20

Module 5

Wave Motion

Distance Learning

Alberta EDUCATION

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Physics 20

Module 5

Wave Motion

Alberta
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Student Module
Module 5
Wave Motion
Alberta Distance Learning Centre
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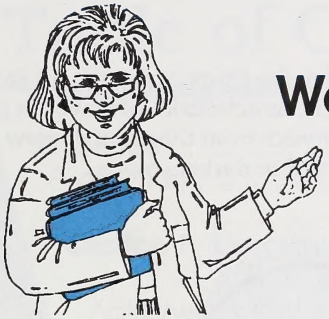
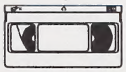


Welcome to Module 5!

We hope you'll enjoy your study of *Wave Motion.*

To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.



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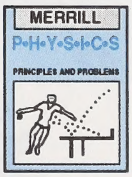
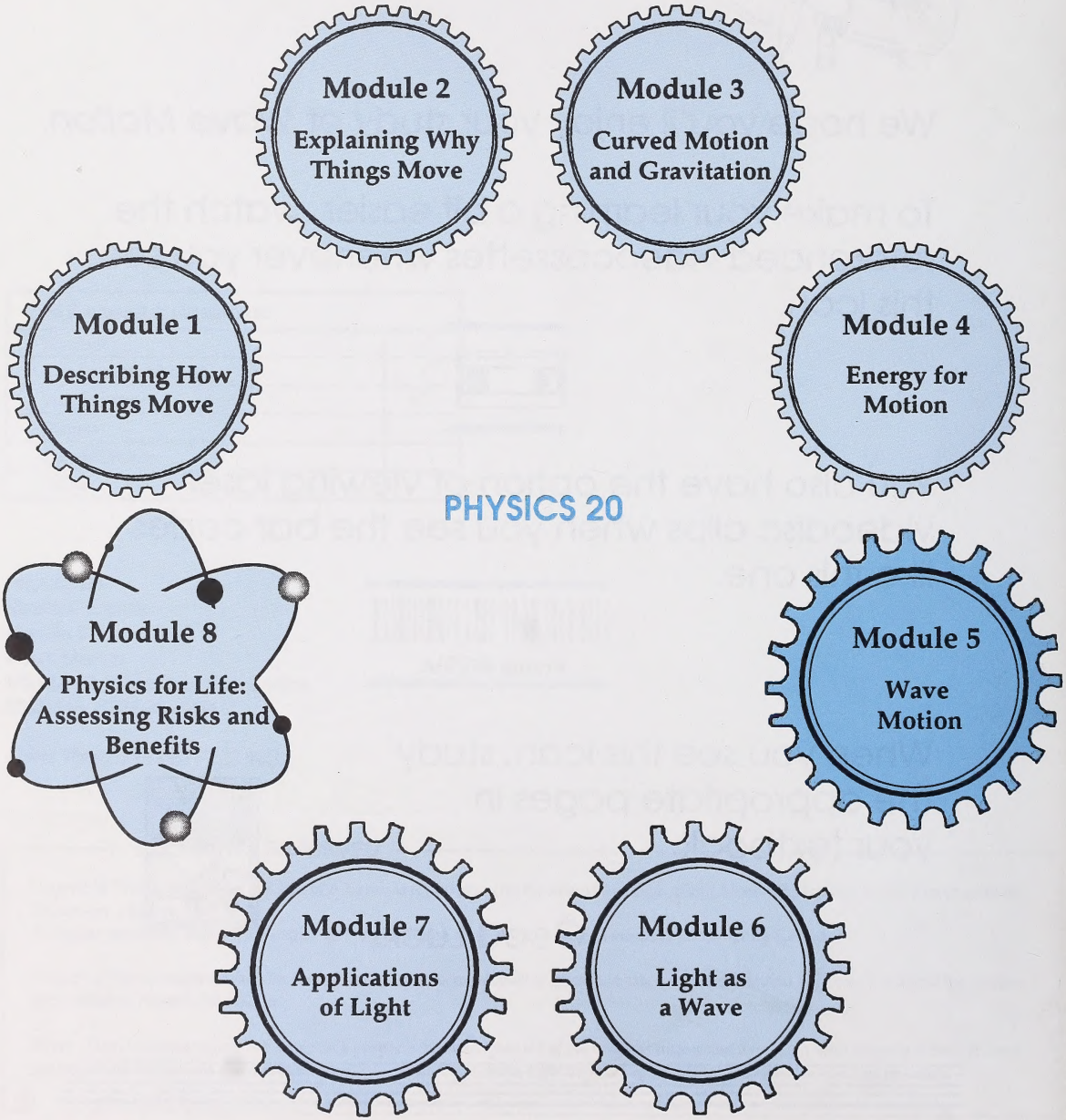
When you see this icon, study the appropriate pages in your textbook.



Good Luck!

Course Overview

This course contains eight modules. The first four modules involve the study of motion on Earth and in the heavens. Modules 5, 6, and 7 investigate the properties and characteristics of waves in general and light waves. The last module is an introduction to nuclear physics from the point of view of risk/benefit analysis. The module you are working in is highlighted in darker colour.



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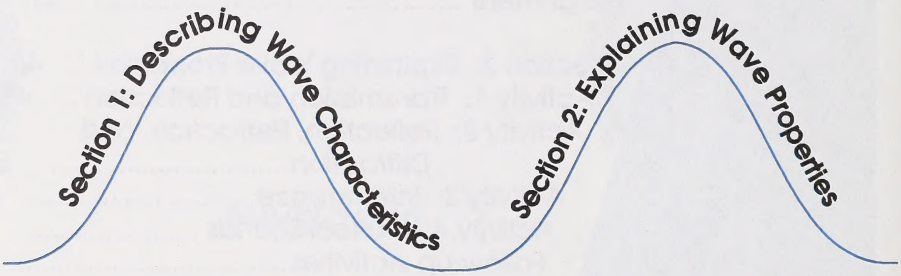
OVERVIEW

Imagine that you have two tickets for you and a friend to hear your favourite performer in concert. After much anticipation, the house lights go down, the stage lights come up, and the music starts. The whole auditorium is vibrating with sound.

Another friend missed the concert and asked what it sounded like. How would you describe the sounds? Would you be able to explain how the sounds were made? Would you be able to explain that the music reached your ears through sound waves?

In this module you will learn how to describe the characteristics of many types of waves, including sound waves. You will also investigate the properties of waves and you will see how these properties influence the sounds created by musical instruments.

Module 5: Wave Motion



Evaluation

Your mark in this module will be determined by your work in the Assignment Booklet. You must complete all assignments. In this module you are expected to complete two section assignments. The mark distribution is as follows:

Section 1 Assignment	40 marks
Section 2 Assignment	60 marks
TOTAL	**100 marks**

Section

1 Describing Wave Characteristics

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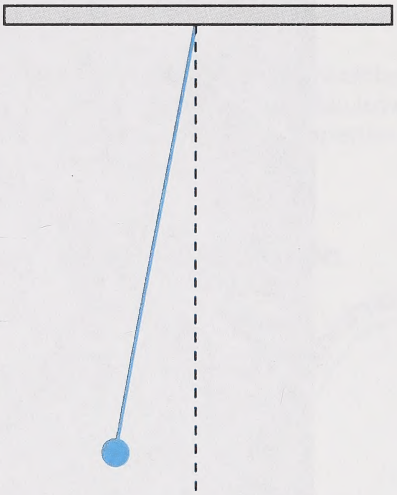
Have you ever swum in an ocean or indoor wave pool? If you have ever experienced body surfing or diving into large waves, you already know about the power of wave motion. People who try this for the first time are often surprised by the energy that is carried by waves. In fact, many indoor wave pools warn swimmers that swimming in waves is much more tiring than swimming in an ordinary pool because of the large amplitude, considerable speed, and regular frequency of the waves.

In this section you will learn to describe the characteristics of waves. You will investigate how these characteristics are related to each other and you will then develop an equation for all waves. In the last activity you will apply these ideas to the description of sound waves.

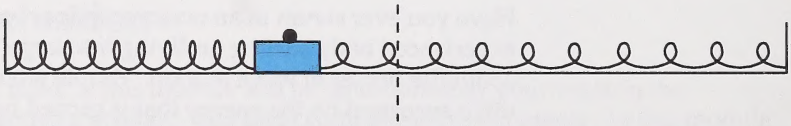
Activity 1: What Is a Wave?

No matter how you answer the question asked in the title of this activity, you will probably be forced to refer to vibrations. Before beginning a study of waves, you should review a few key ideas from Module 4.

1. Label the following diagram of the pendulum to show the important characteristics that make it an example of simple harmonic motion.



2. The following diagram shows a mass vibrating between two springs. Label the diagram to show the important characteristics that make this an example of simple harmonic motion.



Check your answers by turning to the Appendix, Section 1: Activity 1.

Wave motion is based on the idea of a restoring force returning an object to its equilibrium position. The main difference between wave motion and simple harmonic motion is that wave motion involves many oscillating objects instead of just one.

Investigation: Observing Waves

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☐ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Purpose

In this investigation you will observe wave behaviour and then link these observations to simple harmonic motion and the definition of a wave.

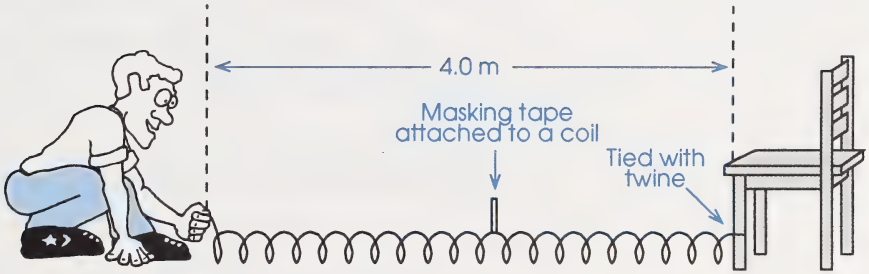
Materials

You will need the following materials for this investigation:

- thick string or twine
- masking tape
- a long coil spring with a 7-cm diameter
- a chair
- an area of empty floor space that is about 1 m by 5 m

Procedure and Observations

- Set up the apparatus as shown in the following diagram.



- Be sure that the masking tape has been attached to the middle of the spring and that one end of the spring has been securely tied with the twine to the chair leg. If the chair is too light, it might move or fall over, so it may be necessary to weight it down with some books. Another alternative would be to ask someone to hold one end of the spring.

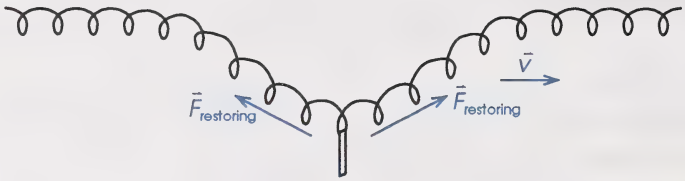
- Quickly snap your hand holding the spring sideways. Observe the disturbance that travels in the spring.

- Repeat this sideways movement several times.

Caution

3. Describe the movement of the disturbance as it travels in the spring.

The following diagram shows what the spring might look like as the disturbance travels by the piece of tape.



Note that the restoring forces on either side of the tape tend to pull at an angle.

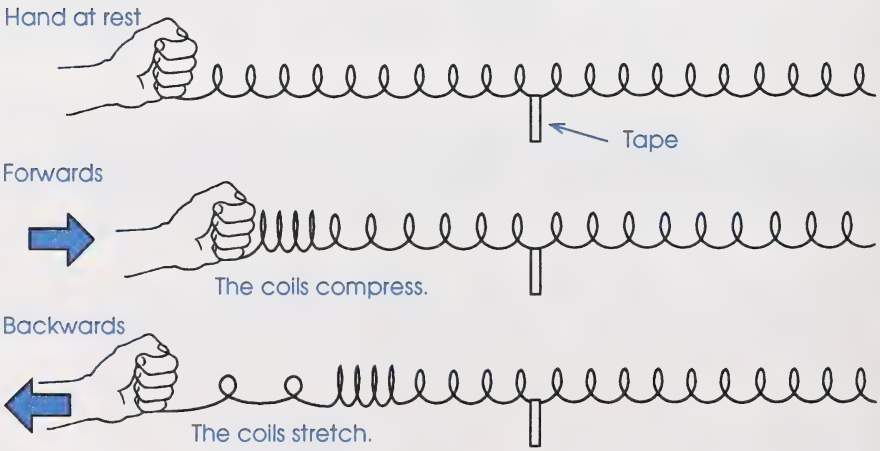
4. Draw the **net** restoring force and the equilibrium position for the spring on the previous diagram.

   - Verify your answer to the previous question by observing the motion of the tape as you repeatedly move your hand sideways and back.

5. Compare the displacement of the tape to the direction of the net restoring force when a disturbance passes through the spring.

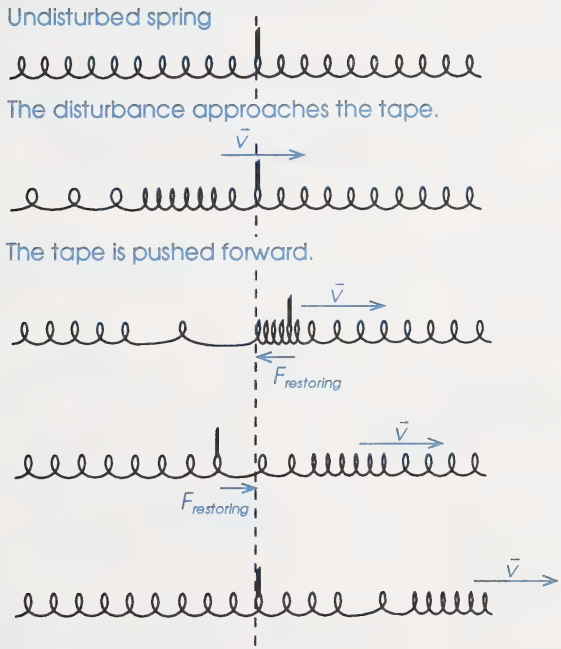
Up until this point in the investigation, the movement of the tape (and spring) could be classified as transverse since the tape and the spring move across the movement of the disturbance. However, there is another way to send vibrations down the spring.

   - Move your hand away from you and back as shown in the following diagrams here and on the following page.



6. Describe the movement shown in the previous diagram as it travels in the spring. How does the piece of tape move?

The following series of diagrams shows what the spring might look like as this type of disturbance travels by the piece of tape. The restoring force has been added to the diagram.



7. Label the equilibrium position on the previous diagram.

8. Compare the displacement of the tape to the direction of the restoring force.

longitudinal – running lengthwise

The movement of the tape in the previous diagram can be described as **longitudinal** because the tape moves in the same direction as the disturbance.

Analysis

Since the tape was forced through a distance, work was done on the tape. In other words, the work done by your hand to move the free end of the spring caused energy to be transmitted through the spring to the piece of tape, where work was done on the tape. After the disturbance eventually subsided, the spring was still intact and all the

coils were still connected in the same order. You were able to transfer energy through the spring to the tape without transferring matter.

wave – the transfer of energy through vibrations

A **wave** transfers energy from one point to another without transferring matter. The energy is transferred through vibrations.

medium – the material that vibrates and carries the energy of the wave

In this investigation the spring acted as the **medium** for the waves. The spring allowed vibrations to pass from your hand to the tape.

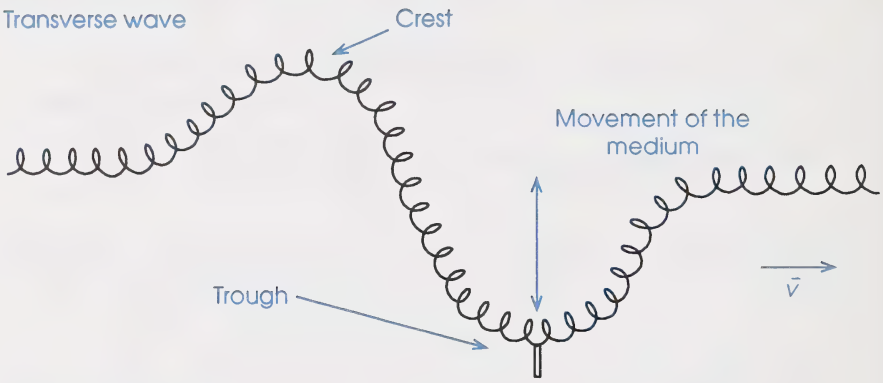
You actually made two types of waves in this investigation.

transverse wave – a wave in which the particles of the medium vibrate perpendicular to the velocity of the wave

Transverse waves are the type of waves usually drawn in books. Transverse waves have **crests** and **troughs**.

crest – a region of positive displacement on a transverse wave

trough – a region of negative displacement on a transverse wave

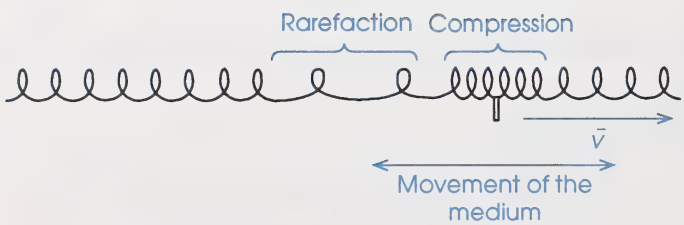


longitudinal wave – a wave in which the particles of the medium vibrate parallel to the velocity of the wave

Longitudinal waves are difficult to draw. Sometimes they are called "push waves" because they are created by pushing the particles of the medium together and then pulling them apart. Longitudinal waves have **compressions** and **rarefactions** instead of crests and troughs.

compression – a region where the particles of the medium are pushed closer together in a longitudinal wave

rarefaction – a region where the particles of the medium are pulled further apart in a longitudinal wave



In both transverse and longitudinal waves, energy is transferred through the medium by vibrations.

Conclusions

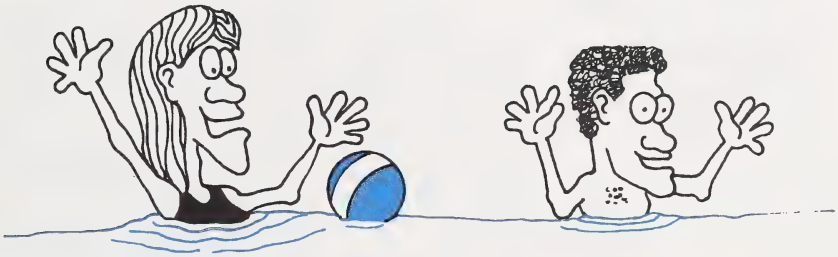
9. Explain why waves require a tension or restoring force in order to travel through a medium.

Applications

10. Imagine that you are in a pool with a group of friends playing catch with a water polo ball. One of your friends has turned away from you and you want to get his attention.

    a. How could you transfer energy to your friend by transferring matter?

    b. How could you transfer energy to your friend without transferring matter?



11. People can actually use their bodies as particles in a medium to form a wave. In each of the diagrams, determine if the wave is transverse or longitudinal and label the appropriate parts.

    a. Fans form "the wave" at a football game.

b. People push in the line for football tickets.

Terminology

To complete this introduction to waves, there are still a few more terms for you to consider.

wave pulse – a single disturbance travelling through the medium

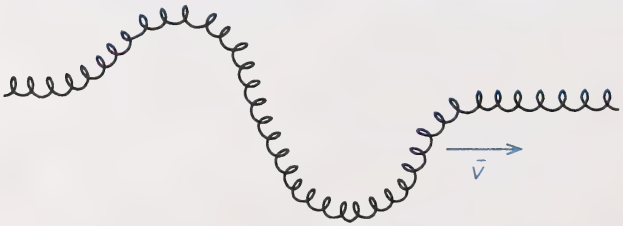
A **wave pulse** is a disturbance that has a beginning and an end. You made a wave pulse when you moved your hand back and forth once. The word *wave* is usually reserved for a series of pulses. You made a wave by moving your hand back and forth more than once.

The following diagrams illustrate the difference between a wave and a wave pulse.

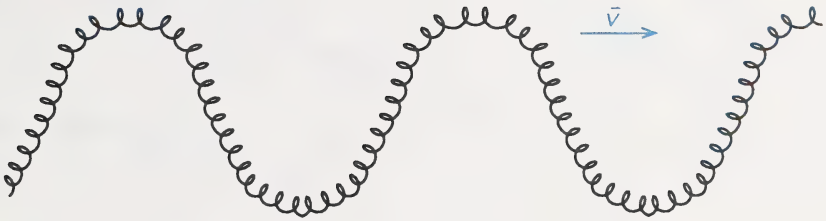
A positive wave pulse

A negative wave pulse

A wave pulse with a positive and negative displacement



A wave

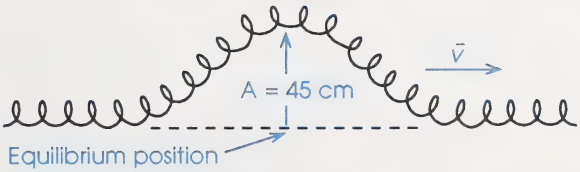


Some of the terms and concepts that you learned in Module 4 are also used to describe wave motion.

amplitude – the maximum displacement of the medium from the equilibrium position

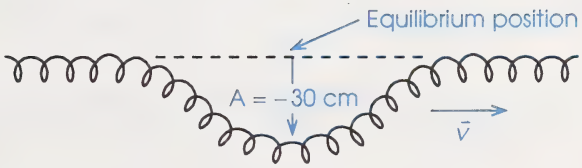
Example 1

This pulse has a positive **amplitude**.



Example 2

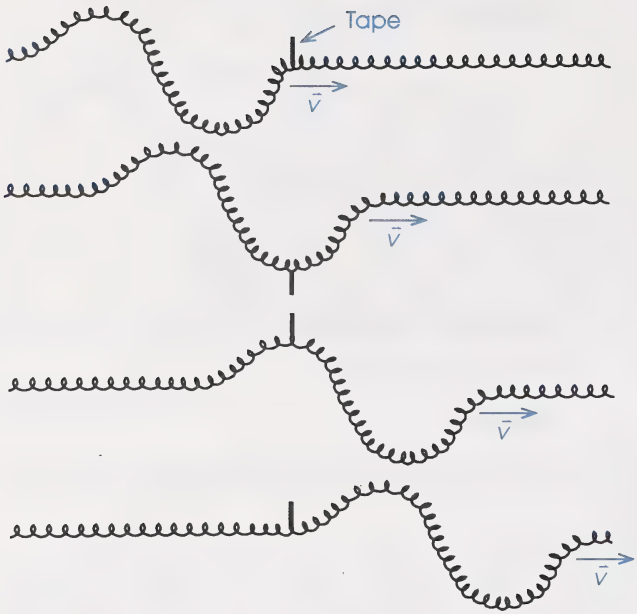
This pulse has a negative amplitude.



Example 3

The diagrams for this example are shown at the top of the next page.

A pulse travelling to the right through a spring encounters a piece of tape attached to the spring. The tape makes one complete vibration, first through the negative amplitude and then through the positive amplitude. This takes 4.0 s.



period – the time taken to make one complete vibration or cycle

frequency – the number of complete vibrations or cycles in one second

The **period** of this wave is 4.0 s. The **frequency** of the wave would be 0.25 cycles per second, or 0.25 Hz, since only one-quarter of a vibration would occur in 1 s. Knowing that frequency and period are inversely related, you could also have found the frequency by using the following method.

$$f = \frac{1}{T} = \frac{1}{4.0\text{ s}} = 0.25\text{ Hz}$$

Example 4

A beach ball floating on a lake vibrates as waves pass under it. The ball reaches its lowest position 25 times in 10 s. Find the period and the frequency.

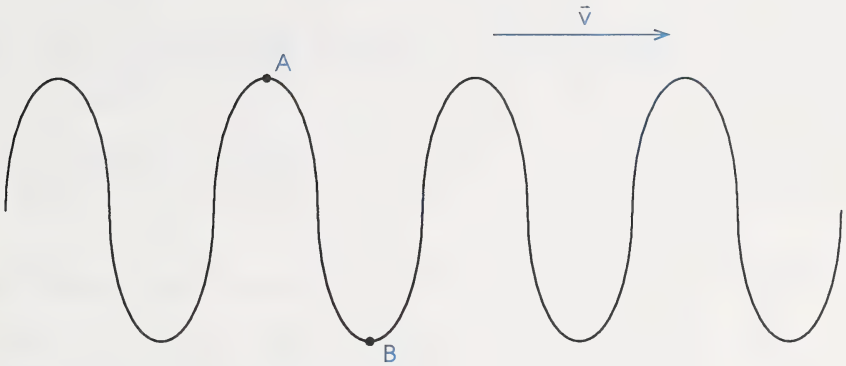
$$T = \frac{10\text{ s}}{25\text{ cycles}} = 0.40\text{ s}$$

$$f = \frac{25\text{ cycles}}{10\text{ s}} = 2.5\,\frac{\text{cycles}}{\text{s}} = 2.5\text{ Hz}$$

or

$$f = \frac{1}{T} = \frac{1}{0.40\text{ s}} = 2.5\,\frac{1}{\text{s}} = 2.5\text{ Hz}$$

12. Waves travelling to the right in a spring make the following pattern:



a. Draw in the equilibrium position for this wave.

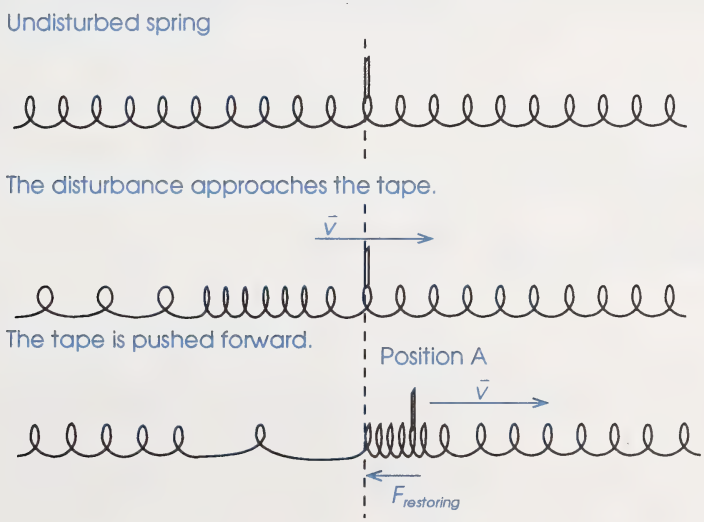
b. Use a ruler to measure the amplitude for points A and B.

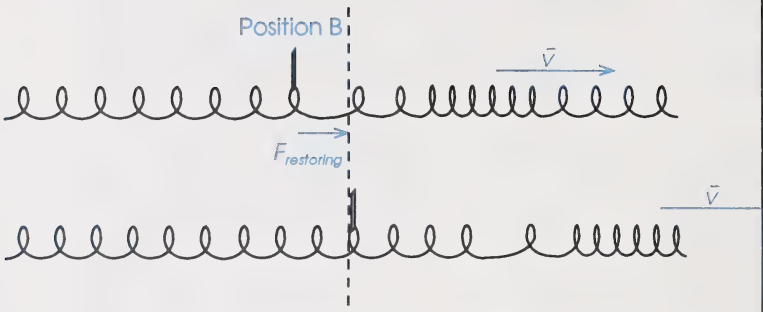
c. Draw the net restoring force at points A and B.

d. Is this wave transverse or longitudinal? Explain your answer and label the diagram appropriately.

e. The particles in this spring vibrate 66 times in 30 s. Calculate the period and frequency for this wave.

13. Waves travelling to the right in a spring make the pattern shown here and at the top of the next page.





a. Use a ruler to measure the amplitude for the tape in positions A and B.

b. Is this wave transverse or longitudinal? Explain your answer and appropriately label the spring that is labelled with position A.

c. The coils in this spring make 96 vibrations in 60 s. Calculate the period and frequency for this wave.

Check your answers by turning to the Appendix, Section 1: Activity 1.

In the next activity you will investigate the factors that determine the frequency of a wave.

Activity 2: Wavelength and Frequency

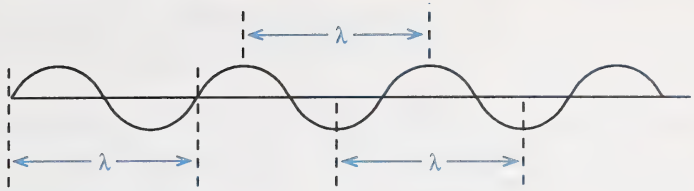
What factors influence the frequency of a wave? In this activity you will examine this question through an investigation. Before you begin, you need to know what **wavelength** is and how it is measured.

wavelength – the distance from a point on one wave to the corresponding point on the next wave

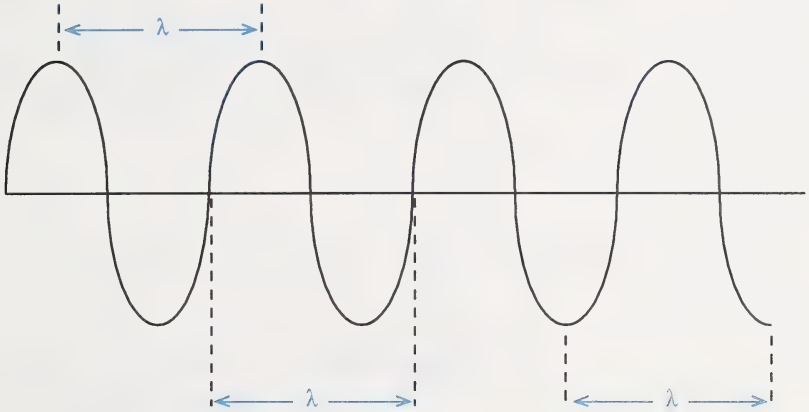
Wavelength

The diagrams that follow show two waves with different wavelengths. The symbol for wavelength is lambda (λ), a letter from the Greek alphabet.

The wavelength of a wave is a measurement that describes the length of one complete wave pattern. Wavelength can be measured from crest to crest, from trough to trough, or between any two corresponding points on adjacent waves.



Wavelength = 29 mm



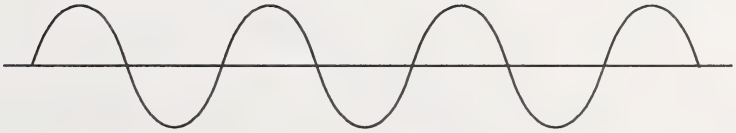
Wavelength = 31.5 mm

1. Use a ruler to double check the previous diagrams. Does measuring from crest to crest give the same value as measuring from trough to trough?

2. Determine the wavelengths of the following waves by measuring with a ruler. Check your answers by measuring the wavelength at different locations.

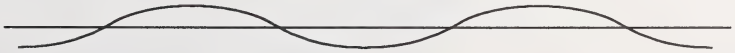
a.

b.

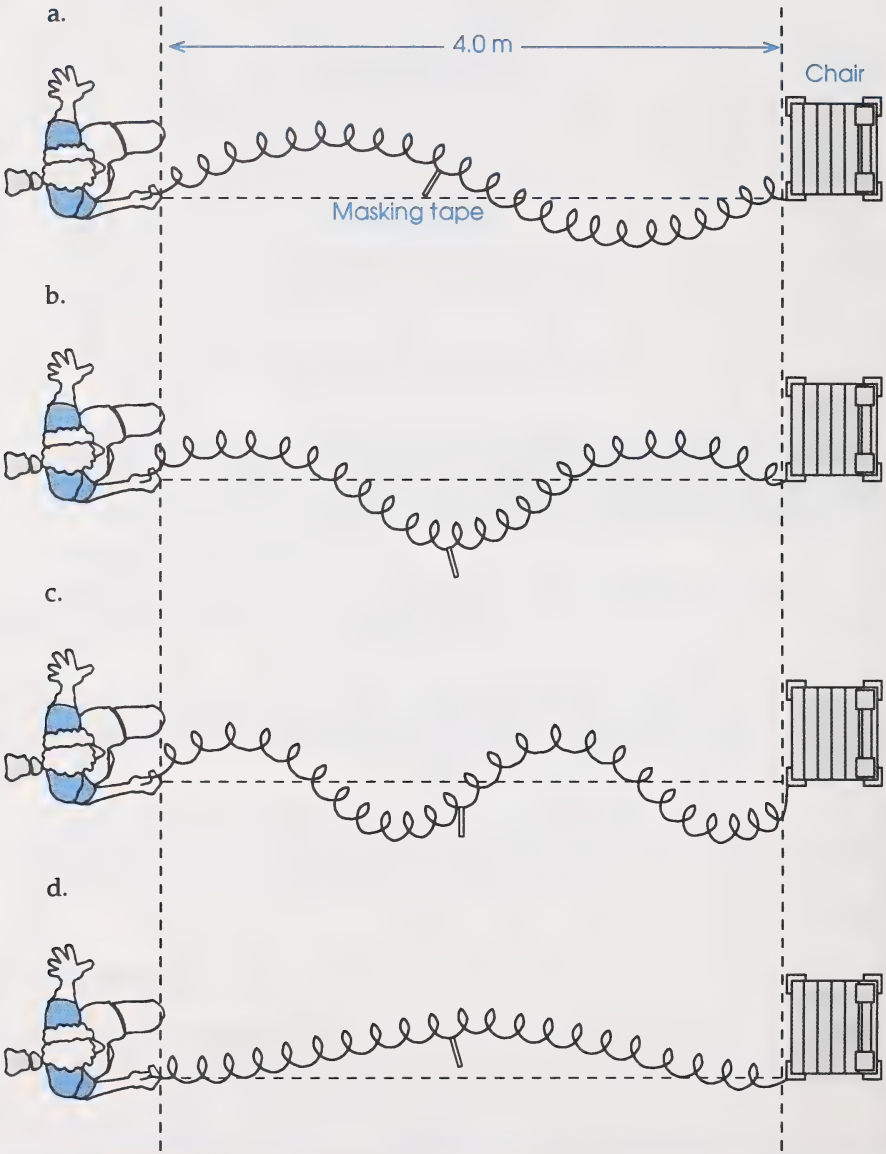


c.

d.



3. A student sits in a hallway with a long spring. The spring is stretched so that the distance between the end anchored to the chair and the end in the student's hand is exactly 4.0 m. Determine the wavelength by examining the top view of the diagram.



Check your answers by turning to the Appendix, Section 1: Activity 2.

In the next investigation you will create and evaluate the wave patterns discussed in question 3.

Investigation: Connections Between Wavelength and Frequency

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☐ F. Evaluating

Purpose

In this investigation you will collect data to determine the relationships between wavelength, frequency, and period.

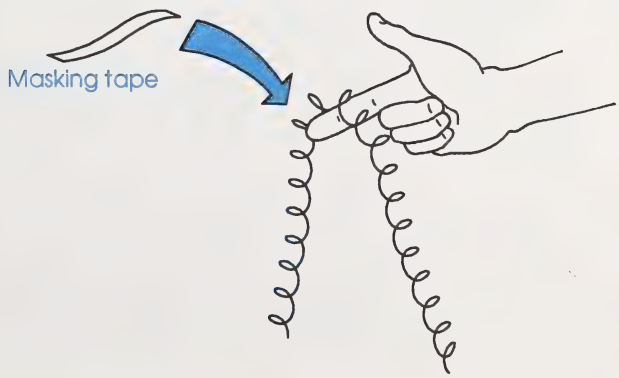
Materials

You will need the following materials for this investigation:

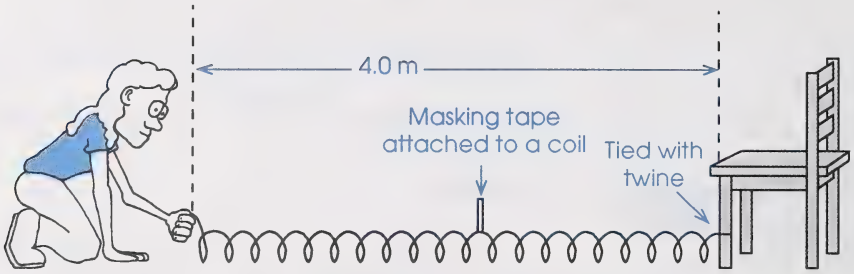
- a metre stick or tape measure
- a stopwatch
- a long spring with a diameter of less than 3 cm
- a piece of masking tape
- strong string or twine
- a chair
- a partner to help count the number of vibrations

Procedure

- Find the middle of the spring and attach a piece of tape to the middle coil. This can be done by holding the middle of the spring above the floor and adjusting the length of the spring hanging on each side. When the length on each side is equal, attach the tape to the middle coil.



- Set up the spring and the rest of the apparatus as shown in the following diagrams.



- You will create the four wave patterns shown in question 3.

4. Refer back to your answers for question 3. Since this investigation recreates the waves discussed in question 3, the wavelengths that you found are the same as those for this investigation. Record the wavelengths from question 3 into the data chart on the following page.

standing wave – a wave which appears to stand still due to the interference of two identical waves

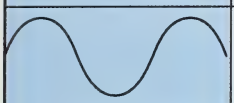
To create each of the wave patterns shown in question 3, you have to make a **standing wave**. Standing waves only occur at a precise frequency, so you will have to discover which frequency produces each pattern. You will learn more about standing waves later in the module.

5. Use a trial and error technique to discover the rate of vibration that produces the first pattern. Once the wave pattern is produced, count the number of vibrations that your hand makes in 30 s. At the same time, have your lab partner watch **one** of the crests and count the number of times that this crest occurs in 30 s. Record these values on the data chart. Remember that in order to make one vibration, your hand and the crest must move to one side and then back.

6. Repeat the previous step for the other three wave patterns. Record the results on the data chart.

7. Calculate the period and frequency of your hand and the period and frequency of the wave crest for each pattern. Record your answers on the data chart.

Data

Data for Standing Waves Made in a Spring							
Wave Pattern	Wavelength (m)	Your Hand			The Wave		
		Vibrations in 30 s	Frequency (Hz)	Period (s)	Vibrations in 30 s	Frequency (Hz)	Period (s)
							

Analysis

8. Your hand is the source of vibrations in the spring and therefore is the source of the wave. Compare the frequency of your hand to the frequency of the wave. Compare the period of vibration for your hand to the period of vibration for the wave. How are the period and frequency of the source of a wave related to the period and frequency of the wave?

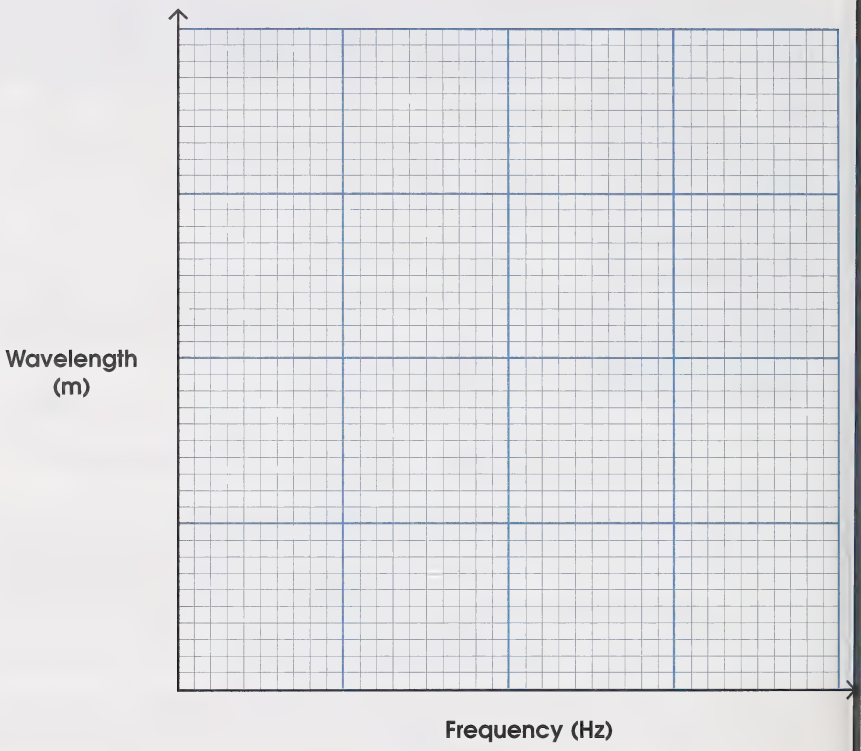
The answer to the previous question provides an important guideline that can be applied to many types of waves: **the frequency of the wave depends on the frequency of the source**. You will find it useful to remember this idea.

For example, you may have had the experience of hearing squeaking sounds when walking over old snow on very cold days. What does it mean if the sound waves coming from the snow on the bottoms of your boots have a high frequency? It must mean that the source of the sound wave is also vibrating at a high frequency. In this case, the old snow has many ice crystals throughout it which tend to snap and vibrate as you step on them.

Another illustration of the connection between source frequency and wave frequency could be found while listening to your favourite radio station. A glance at the dial might tell you that the radio waves have a frequency of 95.6 MHz. How often would the electrons in the broadcast antenna have to vibrate to be the source of these waves? Using the guideline suggested by this investigation, the electrons must also be vibrating at 95.6 million times per second.

9. Compare the wavelength of the wave to the frequency of the wave. How are these variables related?

10. Confirm your answer to the previous question by plotting a graph of the wavelength versus the frequency of the wave.



The shape of your graph should confirm your answer to question 9. Increasing the frequency decreases the wavelength.

11. Do you think that the previous graph could over extend to touch the x-axis? Explain your answer by referring to basic ideas about waves.

12. Do you think that the previous graph could ever extend to touch the y-axis? Explain your answer by referring to basic ideas about waves.

It will be helpful for you to remember the inverse relationship between wavelength and frequency throughout the rest of this module, especially when you study sound. High frequency sounds have a small wavelength, while low frequency sounds have a large wavelength. The pipes of a pipe organ illustrate this idea best. The low frequency sounds require very long pipes since the wavelength is so large, while the high frequency sounds have their small wavelengths accommodated by shorter pipes.

Now reconsider the data that you collected, but this time focus on the relationship between the wavelength and the period.

13. How does the wavelength of a wave relate to the period of a wave?

14. Confirm your answer to the previous question by plotting a graph of the wavelength versus the period of the wave.

15. Find the slope of the last graph. Be sure to include units in your calculations.

16. What do the units for the slope suggest the slope means?

17. Confirm your answer to the previous question by measuring the distance and the time for a pulse on your spring. Stretch the spring out to a 4.0-m length again. Determine the distance and time for the wave to make two round trips on your spring. A single round trip has the pulse move from your hand to the chair and then back to your hand. Two round trips would double this. Although you can't see the pulse return on the second round trip, you should be able to feel it in the hand holding the spring.

Conclusions

18. What determines the period and the frequency of a wave?

19. How are wavelength and frequency related?

20. What does the slope of a wavelength versus period graph represent?

Check your answers by turning to the Appendix, Section 1: Activity 2.

In the next activity you will learn more about calculating the speed of a wave and you will begin to apply this knowledge to a variety of situations.

Activity 3: Universal Wave Equation

Suppose you were able to use a very accurate timing device to measure how long it took for pulse to travel down a spring. The sample data below represents the results of such an experiment.

Data for a Pulse Travelling in a Spring			
Trial	Distance (m)	Time (s)	Speed (m/s)
1	16.0	1.80	
2	8.0	0.90	
3	4.0	0.45	

1. Calculate the speed for each trial and enter the values in the chart.

2. Should the distance used affect the value for the speed of the pulse? Explain your answer.

Check your answers by turning to the Appendix, Section 1: Activity 3.

What if the distance chosen for the wave to travel was exactly one wavelength? The corresponding time would be the time for one wavelength, or the time for one cycle, which is the period for the wave.

The following flow chart shows the equation that results.

$$v = \frac{d}{t}$$

Substitution of wavelength and period

$$v = \frac{\lambda}{T}$$

Rearrange the equation.

$$v = \lambda \frac{1}{T}$$

Substitute frequency for the inverse of the period.

$$v = \lambda f$$

universal wave equation – The speed of a wave equals the wavelength multiplied by the frequency.

This equation is a very important one in physics because it can be applied universally to all types of waves. For this reason it is called the **universal wave equation**.

It is worthwhile to pause and note the future topics in Physics 20 and 30 that use the universal wave equation. The production of sound in musical instruments uses this equation to predict the conditions for resonance. The colors of light each have a characteristic frequency and a corresponding wavelength that, when multiplied together, produce the speed of light. The speed of light and the universal wave equation are also significant to electromagnetic waves, which are studied in Physics 30. Electromagnetic waves include radio waves, radar, microwaves, infrared radiation, visible light, ultraviolet radiation, x-rays, and gamma rays. You'll be introduced to gamma rays in the last module of Physics 20.

The following examples illustrate some applications for this equation.

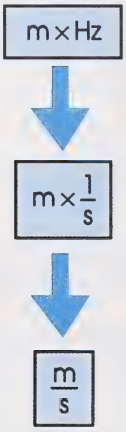
Example 1

A FM radio station sends out radio waves at a frequency of 101.5 MHz. If the wavelength of these waves is 2.96 m, how fast do the radio waves travel?

$$f = 101.5 \text{ MHz}$$
$$= 1.015 \times 10^8 \text{ Hz}$$
$$\lambda = 2.96 \text{ m}$$
$$v = ?$$

$$v = \lambda f$$
$$= (2.96 \text{ m})(1.015 \times 10^8 \text{ Hz})$$
$$= 3.00 \times 10^8 \text{ m/s}$$

Multiplying metres by hertz gives you metres per second (shown in the previous calculation). The flow chart should help you understand how these units are calculated.



Substitution (1 Hz = 1 cycle/s)

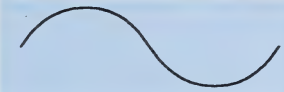
Example 2

The highest frequency sound that most humans can hear is 20 000 Hz. If this sound wave travels at 342 m/s, what is its wavelength?

$$f = 20\,000 \text{ Hz}$$
$$v = 342 \text{ m/s}$$
$$\lambda = ?$$

$$v = \lambda f$$
$$\lambda = \frac{v}{f}$$
$$= \frac{342 \text{ m/s}}{20\,000 \text{ Hz}}$$
$$= 1.71 \times 10^{-2} \text{ m}$$

3. Test the universal wave equation with the data from the investigation in Activity 2. Copy the data for the wavelength and the frequency of the wave from the investigation into the following chart. Complete the chart by calculating the speed of the wave.

Applying the Universal Wave Equation to Waves on a Spring			
Wave Pattern	**Wavelength (m)**	**Frequency (Hz)**	**Speed (m/s)**
			

4. Does doubling the frequency double the speed? Use the data from the chart to support your answer.

5. Does doubling the wavelength double the speed? Use the data from the chart to support your answer.

The universal wave equation is not as straightforward as it looks. Since wavelength and frequency are inversely related, doubling one nearly halves the other, leaving the speed unchanged. When you listen to music from a stereo located on the other side of the room you don't hear the high frequency sounds before the low frequency sounds, nor do you hear the large wavelength sounds before the small wavelength sounds. All these sounds reach your ears at the same time.

The speed of a wave does not depend on the wavelength or the frequency. The speed of a wave is determined by the properties of the medium. In general, a fast medium's particles are held in place with large restoring forces. In addition, the particles have little inertia (mass) and can react very quickly to the vibrations. A slow medium's particles would be held in place with small restoring forces. The particles would have a large inertia and would react slowly to the vibrations.

The following chart illustrates the effects of different media on sound waves.

The Speed of Sound in Various Media	
Desciption of the Medium	**Speed of Sound (m/s)**
Air at 0°C	331
Air at 20°C	343
Water	1440
Stainless Steel	5790

6. Which medium's particles are the closest together, the most elastic, and held in place with the largest restoring forces?

7. Why do you think that sound waves travel faster in air at 20°C than in air at 0°C?

8. A tuning fork vibrates at a frequency of 262 Hz. Calculate the wavelengths of the sound wave created if it travels in the following media.

   a. air at 20°C

   b. water

   c. stainless steel

The answers to the last question illustrate an important point about the universal wave equation. Since speed is determined by the medium and frequency is determined by the source, wavelength has no choice but to depend on both the medium and the source.

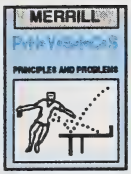
$$v = \lambda f$$

Rearrange the equation.

$$\lambda = \frac{v}{f}$$

Speed depends on the medium.

Frequency depends on the source.



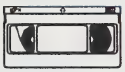
9. To practise applying the universal wave equation, do problems 8, 9, 12, and 13 on page 305 of your textbook.

Check your answers by turning to the Appendix, Section 1: Activity 3.

PATHWAYS

If you have access to the video entitled *The Properties of Waves (Non-Light)*, do Part A. If you do not have access to this video, do Part B.

Part A



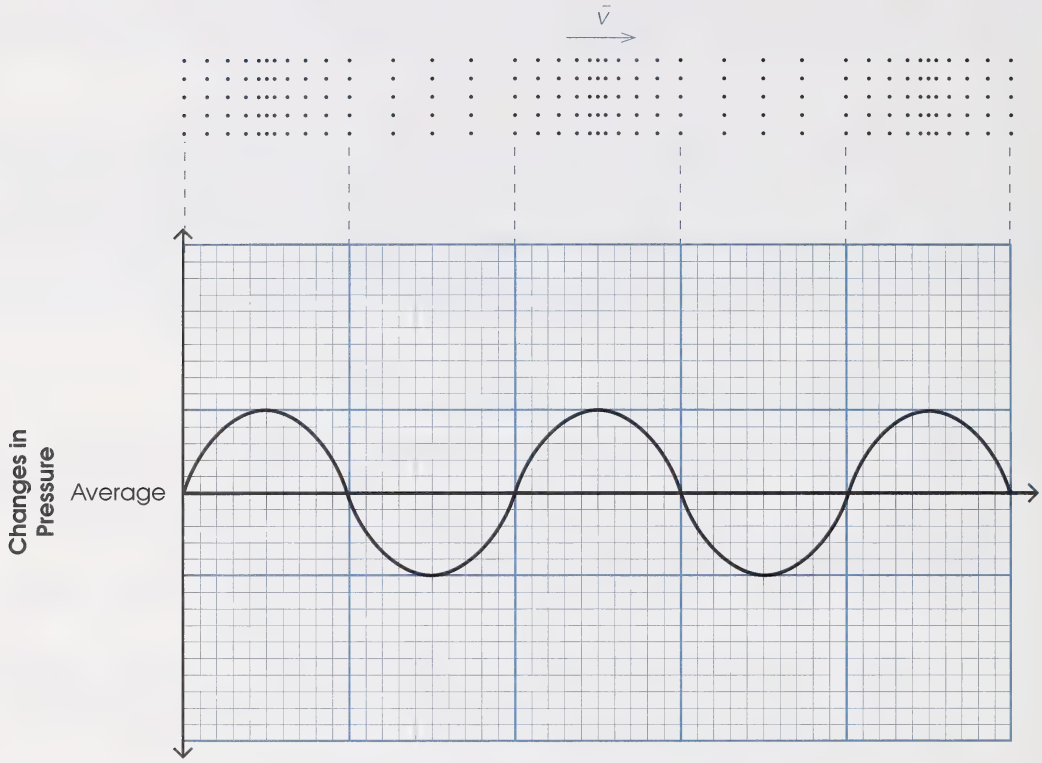
This video will give you an opportunity to see applications of many of the topics discussed so far in this module. Be sure to preview the following questions before you watch the video. As you watch the program, stop the tape as necessary to answer the accompanying questions.

As soon as the video begins to discuss the topic of refraction, stop the tape.

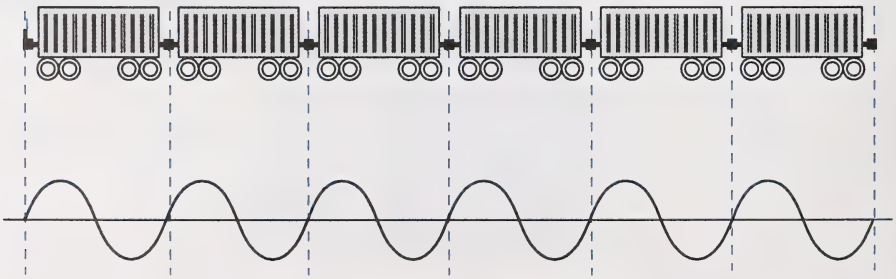
10. Use the following format to create a chart summarizing the wave types shown in the video. Fill in the chart using the information from the video. Adjust the size of your chart according to the length of your answers.

Comparing Wave Types			
Wave Type	**Is the wave transverse or longitudinal?**	**What provides the restoring force for this wave?**	**What is an example of this wave?**
Tension Wave			
Ripples			
Gravity Wave			
Shear Wave			

11. This diagram and graph both represent a sound wave. Label the compressions and rarefactions to show how they relate to the graph of changes in pressure.



12. This diagram shows a comparison between the passing of a train and the passing of a wave. Create a chart that compares the wavelength, frequency, and speed of the wave with the corresponding elements of the diagram of the train.



13. What two aspects of the medium determine the velocity of a wave?

Check your answers by turning to the Appendix, Section 1: Activity 3.

End of Part A

Part B

To review the main differences between the different types of waves, read pages 286 to 289 in your textbook. Pay close attention to the diagrams.

14. What are the differences between mechanical waves, electromagnetic waves, and matter waves?

15. Complete a summary chart which outlines the differences between transverse waves, longitudinal waves, and surface waves. Your chart should be similar to the one shown.

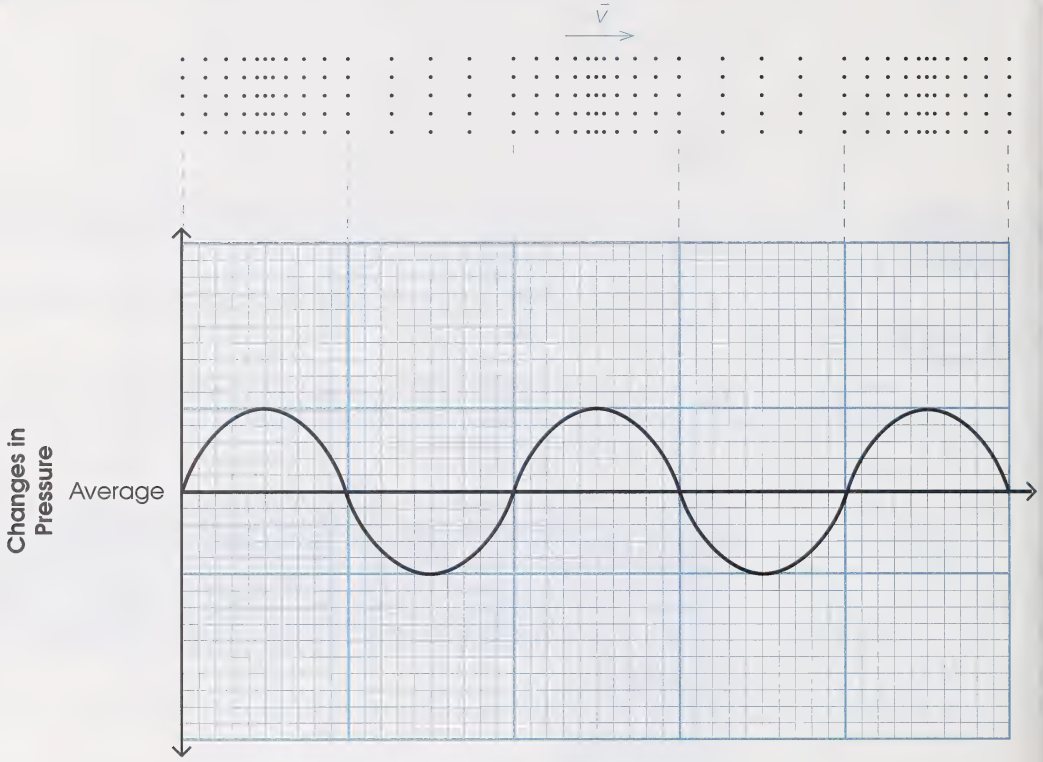
A Comparison of Wave Types			
	Transverse Waves	Longitudinal Waves	Surface Waves
Definition			
Diagram of This Wave Type			
Example of This Wave Type			

Read pages 290 and 291 to review the important measures of wave characteristics.

16. Draw a transverse wave and label the crests, troughs, amplitude, and wavelength.

Read page 308 to learn about sound waves.

17. This diagram and graph both represent a sound wave. Label the compressions and rarefactions to show how they relate to the graph of variations in pressure.



Read from the middle of page 294 to the middle of page 295 in your textbook.

18. What determines the speed of a wave that travels in a rope? Illustrate your answer by describing a rope that would be a fast medium for waves and a rope that would be a slow medium.

Check your answers by turning to the Appendix, Section 1: Activity 3.

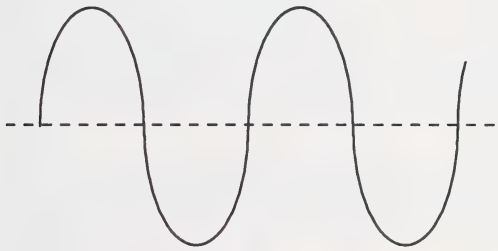
End of Part B

In the next activity you will see how sound waves can be described.

Activity 4: Describing Sounds

In the previous activities you learned how to describe characteristics of waves by measuring certain features of the wave with a metre stick or stopwatch. These measurements create an objective description because terms like wavelength, frequency, and amplitude have precise definitions and measurements. The following question illustrates how well-defined, objective characteristics can be measured.

1. Use a ruler to describe the wavelength and amplitude of the following wave.



The study of sound waves can be done in the same objective manner that you answered the last question. However, the equipment required to allow very careful descriptions of amplitude and frequency can be quite costly.

More often than not, sound is described with subjective characteristics which do not have the same kind of precise definitions and direct methods of measurement. Instead, these characteristics depend on the structure of the ear, the processing of information by the brain, and the psychological aspects of perception. In other words, subjective sound characteristics depend on the opinion of the listener.

Pitch

pitch – a subjective sound characteristic that depends mainly on frequency

Pitch refers to whether a sound is high like a flute or low like a bass guitar. Pitch is determined mainly by the frequency of the sound – the higher the frequency, the higher the pitch, and the lower the frequency, the lower the pitch.

2. Classify the following musical instruments as being either **high-pitched** or **low-pitched**.

   a. piccolo
   b. double bass
   c. kettle drum
   d. triangle
   e. tuba
   f. hand bell

3. Refer to your answer to the previous question. Compare the size of the high-pitched instruments to the size of the low-pitched instruments. Explain this trend in size in terms of the pitch and frequency of the sounds produced.

It is interesting to know that humans can hear pitches that correspond to a frequency range of 20 to 20 000 Hz. This fact is truly astonishing when you express the frequency range as twenty vibrations per second to twenty thousand vibrations per second. This means that a very high pitched source, the air surrounding it, and the sensitive parts of your inner ear are all vibrating back and forth twenty thousand times per second.

The range of frequencies that people can hear tends to vary from one individual to the other. In general, as you get older the highest frequency that you can hear tends to drop. In later life you may only be able to hear sounds that are less than 10 000 Hz. Many animals can hear sounds beyond the frequency range that humans can hear. Frequencies above 20 000 Hz are called ultrasonic. Dogs can hear frequencies above 40 000 Hz, while bats routinely use frequencies over 80 000 Hz. Frequencies below 20 Hz are called infrasonic. These sounds cannot be heard by humans, but they can be felt. Heavy trucks and machinery often vibrate between 6 Hz and 20 Hz, and although the operators can't *hear* the sounds, they can still *feel* them.

Loudness

loudness – a subjective sound characteristic that depends mainly on pressure changes at the ear

Loudness refers to whether a sound is loud and causes large pressure changes at your eardrum, or whether it is quiet and causes small pressure changes. The range of pressure changes that the human ear can detect is astonishing.

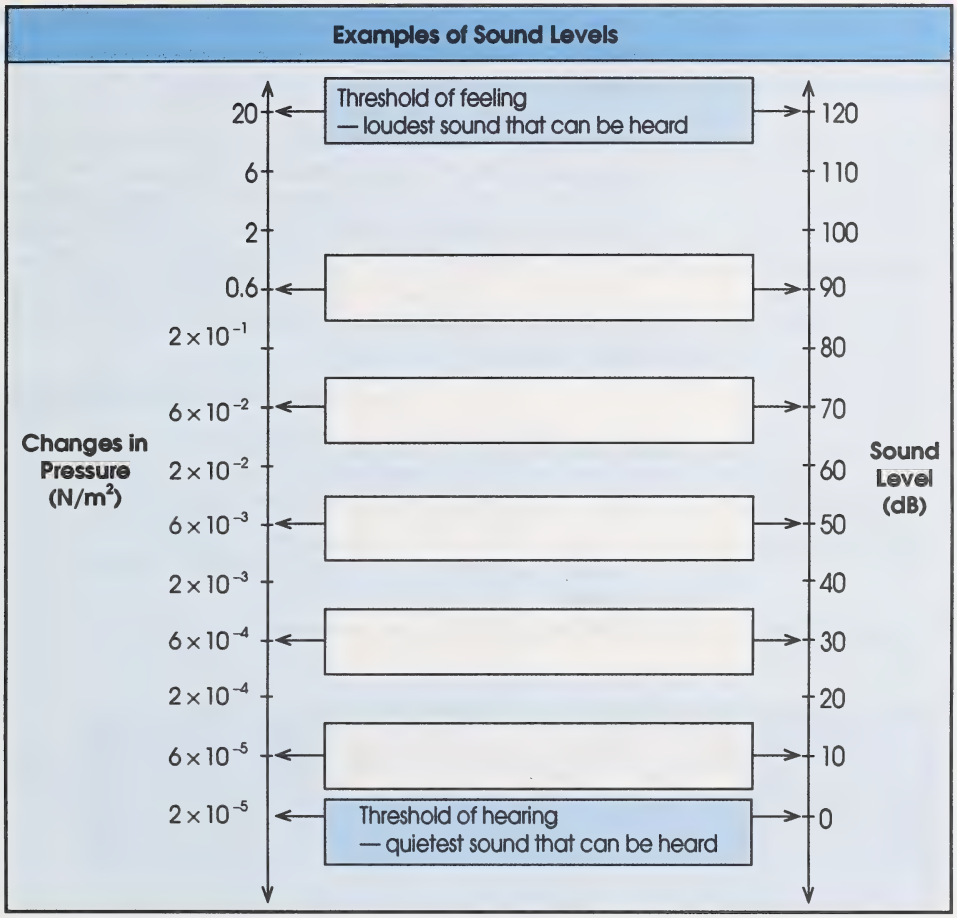
The quietest sound that most people can hear is called the threshold of hearing. This sound corresponds to a pressure change at the eardrum of less than 2×10^{-5} N/m^2.

The loudest sound that most people can comfortably hear is called the threshold of feeling. This sound occurs when pressure changes of 20 N/m^2 occur at the eardrum. At this high level, the sounds actually cause the tiny bones of the ear to tickle or rattle against the walls in the inner ear. Sounds beyond this level are painful.

sound level – depends on the pressure for a given sound compared to the pressure of the most faintly heard sound

Since the range in pressure changes is so large, sound pressures are often measured in terms of **sound level**. The unit for sound level is the decibel (dB).

4. The following chart shows the relationship between pressure changes and the sound levels measured in decibels. Refer to Figure 15-5 on page 312 of your textbook to fill in the blanks on the chart.



The relationship between decibels and pressure changes is not linear. The difference between a soft whisper and the level of conversation is only 40 dB, but this also corresponds to the pressure increasing by a factor of 100.

5. Use Figure 15-5 on page 312 of your textbook to answer these questions.

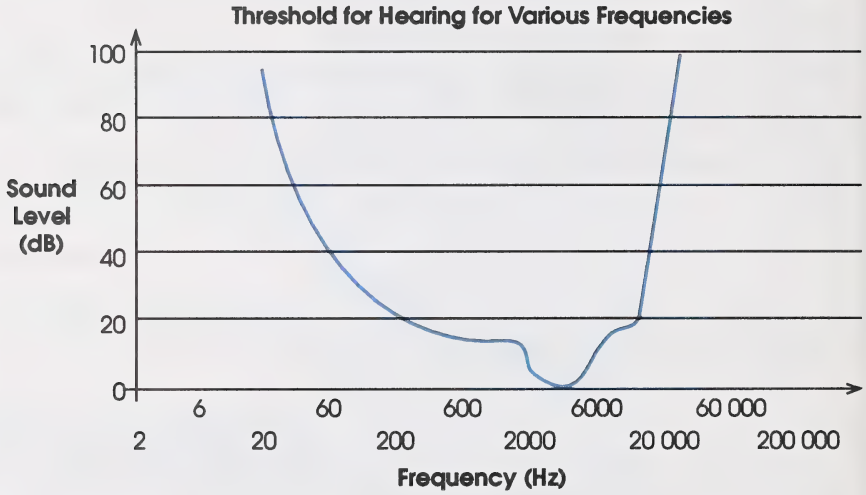
   a. Calculate the difference in the sound levels of a heavy truck and a soft whisper.

   b. Calculate the ratio of pressure changes for a heavy truck and a soft whisper.

c. Use your answers to parts a and b to explain the significance of an 80-dB difference between two sounds.

Although measurements of changes in pressure and sound levels help to show the range of levels in human hearing, these things do not measure loudness. Like pitch, loudness is a sensation which occurs in the mind of the listener.

One attempt to study the perception of loudness involved playing a single frequency of sound while gradually reducing the sound level. When the subjects said they could no longer hear the sound, this established the threshold of hearing for that frequency. The experiment was then repeated for many frequencies. The following graph shows the results of this experiment. Note that the frequency scale has been adjusted to help show the details at the lower frequencies and compress the information for the higher frequencies.



6. Why does the graph not drop below 20 Hz or extend beyond 20 000 Hz?

7. What frequencies of sound are people able to hear with a sound level of 10 dB or less?

8. What frequencies are people able to hear with a sound level of 20 dB or less?

9. A home stereo on low volume produces sound at a level of 30 dB.

   a. According to the previous graph, what frequencies of sound would be inaudible?

b. Based on your experience and your answer to the last question, describe the differences in pitch between music played at a low volume and the same music played at a high volume.

c. Many home stereos have a loudness button. Typically this button will boost frequencies around 100 Hz by 6 dB and those around 10 000 Hz by 3 dB. How does the loudness button improve listening for the low volume 30-dB output?

Quality

quality – the subjective characteristic of a sound that depends on the number and strength of the overtones created

fundamental frequency – the lowest frequency that makes up a sound

overtones – higher frequencies that are created in addition to the fundamental frequency

Quality is the other main characteristic used to describe sounds subjectively. When a single note is played on a musical instrument, more than one frequency of sound is produced. The lowest frequency of the single note is called the **fundamental frequency**. The other frequencies that are created are called **overtones**.

Although two musical instruments may play the same note (fundamental frequency), the number and strength of the overtones produced will be different. This gives the sound produced by each musical instrument its own distinct quality. The quality of a sound is determined by the number and the strength of the overtones which are present.

The following chart illustrates the differences in quality between different sound sources.

Quality of Sound from Different Sources

Source of Sound	Description of Overtones	Description of Quality
A tuning fork is struck lightly on the soft sole of an athletic shoe.	Few overtones are produced and they are relatively weak.	soft, mellow, warm
A middle key of a piano is struck.	About five strong overtones are produced.	rich, full
A tuning fork is struck firmly on a piece of hardwood.	More than six strong overtones are produced.	sharp, harsh, metallic, cold

Examples of quality can be confirmed using a tuning fork in a quiet room. Lightly strike the tuning fork against the soft sole of an athletic shoe and hold it about 30 cm from your ear. Concentrate on the sound that you hear in the first five seconds. Would you describe it as soft, mellow, and warm? Now repeat the process, only this time strike the tuning fork firmly on a piece of hardwood. Concentrate on the sound that you hear in the first five seconds.

10. Describe the differences in sound quality that can be heard after striking the tuning fork on hardwood and striking it on an athletic shoe.

Check your answers by turning to the Appendix, Section 1: Activity 4.

Musical instruments can also produce different quality sounds depending on how they are played. A skillful guitarist can create a sudden change in the mood associated with a piece of music by changing the way the guitar strings are played. When the guitarist uses a plastic pick, a finger nail, or the soft, fleshy part of the fingers to play the strings, the results are sounds with their own distinctive quality. The next time that you are able to watch someone play the guitar, try to observe which methods of plucking the strings produce the warmest sounds and which methods produce the harshest sounds.

In the next investigation you will explore your own perceptions of pitch, loudness, and quality.

Investigation: Singing Glasses

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Purpose

In this investigation you will discover which types of drinking glasses produce the loudest sounds, which types produce the highest pitched sounds, and which types produce the warmest quality of sounds.

Materials

You will need the following materials for this investigation:

- a small saucer with 50 mL of vinegar
- a quiet room
- three different shapes of drinking glasses

All the glasses should be made of glass or crystal and they should not have handles. Ideally, thin-walled glasses with stems work best (wine goblets or brandy snifters).

Some of the possible glass shapes are shown in the following diagram.

Procedure

- Arrange the glasses in a quiet room.
- Make a data chart on which you can sketch the different glasses and compare the pitch, loudness, and quality of the sounds they produce.
- Sketch each glass in the data chart.
- Wash your hands with soap and water before starting.

Caution

- Check to see that the rims of the glasses are clean and free of any chips or cracks. A glass that is cracked or chipped along the rim should not be used for this experiment or for drinking.
- Dip your index finger in the vinegar and begin to slowly rub it around the rim of the largest glass while you firmly hold the bottom of the glass with your other hand.

- If the glass does not begin to sing, dip your finger in the vinegar and try again. Don't worry if drops of vinegar run down the side of the glass. The vinegar is actually cleaning the rim and will help produce good results. The trick is to clean the rim with the first few attempts and then find the right combination of slight downward pressure and speed to make the glass sing continuously.

11. Use the same technique for each of the other glasses to test for pitch. Which glass produces the highest pitch? Which glass produces the lowest pitch? Record your results on the data chart.

12. Repeat the procedure, but this time test each of the glasses for loudness. Which glass produces the loudest sound? Which glass produces the quietest sound? Be careful not to confuse loudness with pitch. Record your results on the data chart.

13. Repeat the procedures one more time to test for quality. Which glass produces the warmest sound? Which glass produces the harshest sound? Record your results on the data chart.

Analysis

Your finger sets up both longitudinal and transverse vibrations within the material in the glass as it travels around the rim of the glass. These vibrations soon excite air molecules and the sound wave travels to your ear.

14. Select the glass that sang the best. Repeat the procedure with the empty glass and then with the glass one-quarter full of water. What changes the most, loudness, pitch, or quality?

15. Predict how the sound will change if the glass is filled three-quarters full of water. Confirm your prediction by repeating the procedure.

16. Are your answers to the last questions consistent with the idea that low-pitched musical instruments generally have larger, more massive parts that vibrate?

Check your answers by turning to the Appendix, Section 1: Activity 4.

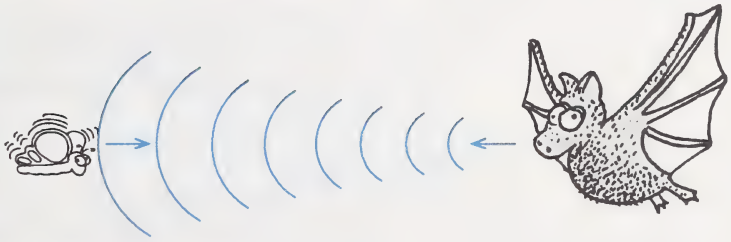
Doppler Effect

Doppler effect – the change in frequency due to the relative motion between a wave source and a receiver

One very interesting application of pitch occurs when an object that is emitting a continuous sound at a constant frequency moves either towards or away from you. The resulting change in pitch is known as the Doppler effect or the Doppler shift.

To understand why the Doppler effect occurs, carefully read from the bottom of page 309 to the bottom of page 310 of your textbook.

17. Examine the photograph on page 306 and the question on page 307 of your textbook. Use this information and the explanation provided on page 310 to complete the drawings of the sound waves on the following chart.

How Bats Locate Flying Insects	
The insect is flying away from the bat.	
The insect is flying towards the bat.	
The insect and bat are flying at the same velocity.	

The previous diagram of the sound waves emitted by the bat are not drawn to scale. A calculation of the wavelength for the sound waves produced by bats will quickly verify that the sound waves shown should be much closer together.

18. If a bat emits a chirp at 82 000 Hz, what is the wavelength of this sound? Consider the speed of sound in air to be 343 m/s.

19. Waves will only reflect off objects that are the same size or larger than the wavelength. Why do bats use sound waves with such high frequencies and short wavelengths?

20. Porpoises use frequencies up to 2×10^5 Hz for underwater navigation and echo location. Explain why the wavelengths created by porpoises are longer than those created by bats. Shouldn't higher frequencies mean smaller wavelengths?

The Doppler effect can be applied to all types of waves. When police use radar to catch speeding motorists, it is actually the Doppler effect on the radar waves which allows them to determine the actual speed of the vehicle.

Check your answers by turning to the Appendix, Section 1: Activity 4.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is advised that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

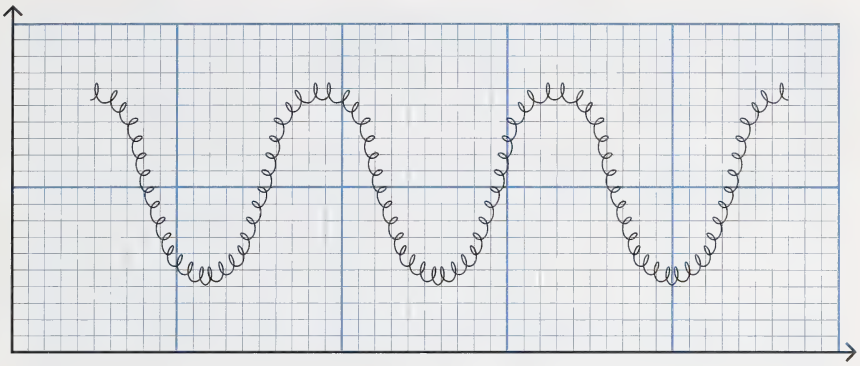
1. Copy the following chart in your notebook and fill it in. You should adjust the size of your chart according to the length of your answers.

Term	Symbol	Unit and Measure	Definition (Point Form)
Amplitude			
Wavelength			
Frequency			
Period			
Speed			

2. Draw labelled sketches showing the parts of a transverse wave and a longitudinal wave. Your sketches must include the crests, troughs, amplitudes, and wavelengths.

3. Examine the following diagram and answer the following questions.

$f = 4.0$ Hz Scale: Each small square represents 1 cm.



a. What is the wavelength (λ) of the wave?

b. What is the amplitude of the wave?

c. Calculate the velocity (v) of the wave.

d. Calculate the period (T) of the wave.

4. Draw and complete a chart with the same headings as the one shown. You will need to adjust the size of your chart according to the length of your answers.

Subjective Sound Characteristic	Factors that Determine This Characteristic	Two Examples that Illustrate This Characteristic
Pitch		
Loudness		
Quality		

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

Do **one** of these three activities.

1. Use pages 318 to 320 of your textbook to write a report about how people hear. Your report should include a labelled diagram of the ear and a short description of how each part works to send sound to the brain.

2. Earthquakes are an example of nature sending huge amounts of energy through seismic waves.

   Go to the library and use either an encyclopedia or science textbook to fill in a chart like the one shown. You will need to draw this chart in your notebook. Adjust the size of your chart according to the length of your answers.

   Once you have the chart completed, answer the questions that follow.

Types of Seismic Waves		
	P	S
Description		
Wave Type		
Relative Speed		

   a. Which wave doesn't pass through the inner and outer cores of the earth?

   b. What is the measuring device used to detect earthquakes and what is its scale?

3. If you have access to laboratory facilities and the laboratory manual that accompanies the textbook, do Experiment 15.1: The Sound Level of a Portable Radio or Tape Player on page 91 of the laboratory manual.

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

In this section you have seen how the terms *frequency, period, wavelength, amplitude,* and *speed* can be used to describe a variety of wave phenomena. The universal wave equation is an especially important equation since it shows the interrelationship of these ideas and can be applied to all types of waves. You have also learned how to describe sound waves in terms of pitch, loudness, and quality.

In the next section you will continue your exploration of wave motion by investigating the behaviour of waves in a variety of circumstances.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

Section

2 Explaining Wave Properties

WESTFILE INC.

When was the last time you spent a summer day at the ocean? Strong breezes and cool water make it a perfect place to be when the temperature is high.

The ocean is also an ideal place to watch the behaviour of waves. Have you ever noticed that waves always arrive with their crests parallel to the beach, no matter which direction they travel off shore? Why do you think this happens?

The trail of waves left by a boat also behaves in a curious way. Have you ever noticed how these waves make a characteristic *V* shape of high crests and deep troughs that follow behind the boat? Anyone who has gone water skiing will tell you that these large crests and troughs can give you a rocky ride if you try to cut across them.

After completing this section, you should be able to answer these questions and others that concern the properties of waves. You will begin by investigating the behaviour of spring waves at boundaries. You will then extend this to an examination of water waves at boundaries. The study of what occurs when waves overlap each other will provide important background information before you finally apply all these ideas to the creation of sound by musical instruments.

Activity 1: Transmission and Reflection

How do waves behave when the medium that they are travelling in suddenly changes? Do the waves simply disappear?

1. Use the definition of a wave to explain why a wave could not vanish.

2. If a wave cannot disappear, where could it go?

Suppose two springs are joined together, as shown in the following diagram. The springs provide different media for waves since the coils of the spring on the left are light and spaced far apart, while the coils on the right are heavy and very close together.

boundary – the junction where one medium meets another

3. Draw an arrow on the previous diagram to show the **boundary** between the two media.

Imagine that a wave is generated in the spring on the left-hand side of the previous diagram. How will the wave behave when it reaches the boundary? You will be able to give a detailed answer to this question by the time you finish this activity. The investigations that follow will allow you to observe waves meeting different types of boundaries.

Investigation: Reflection from a Fixed End

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☐ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Purpose

In this investigation you will determine how waves behave when they encounter a medium that has a much greater density than the original medium.

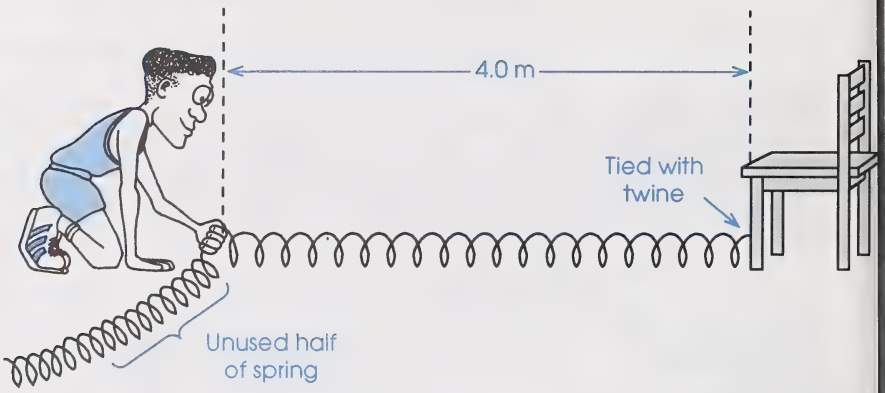
Materials

You will need the following materials for this investigation:

- a long coil spring with a diameter of less than 3 cm
- a chair
- heavy string or twine
- an area of floor space that is approximately 5 m by 1 m

Procedure and Observations

- Set up the apparatus as shown in the following sketch. This investigation works best if you only use half of the spring.



4. Create a transverse pulse that travels down the right side of the spring. Observe the pulse that returns. On which side of the spring is the returning pulse?

5. Create a transverse pulse that travels down the left side of the spring. Observe the returning pulse. On which side of the spring is the returning pulse?

Analysis

incident wave – the initial or incoming wave

reflected wave – the wave that reflects from a boundary

The pulses that you sent towards the chair are called incident pulses. If you sent many pulses at once, they would be called the **incident wave**. The pulses that returned are called reflected pulses. Again, more than one reflected pulse would be called a **reflected wave**.

6. Where is the boundary for this investigation?

Originally, the pulses travelled through the spring. The waves encountered a more rigid and dense medium at the boundary.

7. What is the second medium for the waves in this investigation?

8. Do you think that any of the waves' energy went into the second medium? How could you tell?

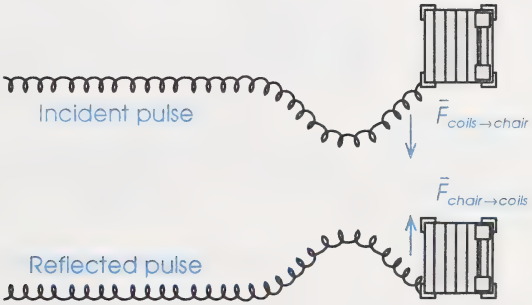
Conclusions

9. Based on your observations, how do waves reflect from the boundary of a more dense and rigid medium?

Check your answers by turning to the Appendix, Section 2: Activity 1.

Interpretation of the Results

Why is the reflected wave inverted? The answer can be explained by Newton's third law of motion. When the wave reaches the boundary, the coils of the spring exert a force on the chair. Since forces always occur in pairs, the chair exerts a force back on the coils of the spring. This force is equal in size and opposite in direction to the original force. The pulse is then reflected upside down (inverted).



10. Write an equation that shows how the forces in the previous diagram act in accordance with Newton's third law.

In the next investigation you will discover what happens when waves encounter a medium that is less rigid.

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [ ] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

Investigation: Reflection from a Nearly Free End

Purpose

In this investigation you will determine how waves behave when they encounter a medium that has a lower density than the original medium.

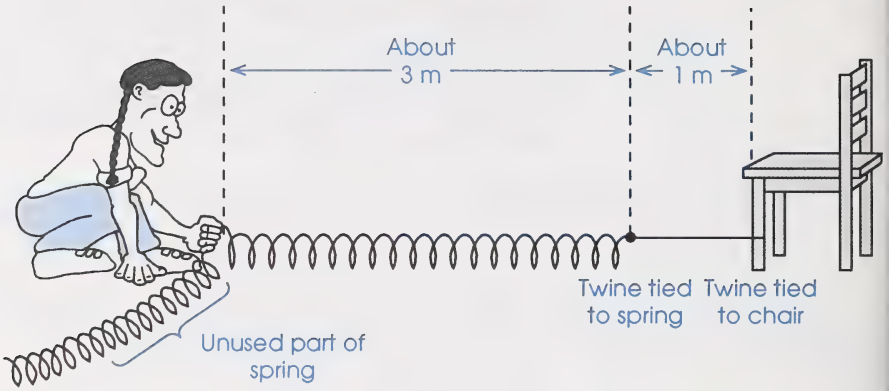
Materials

You will need the following materials for this investigation:

- a long coil spring
- 2 m of heavy string or twine
- a floor area that is about 5 m by 1 m

Procedure

- Set up the apparatus as shown in the following sketch.



- Note that this investigation works best using only about one-third of the spring. This is accomplished by grasping the coils at the one-third point and letting the other two-thirds of the spring rest on the floor.

11. Create a transverse pulse that travels down the right side of the spring. Observe the pulse that returns. On which side of the spring is the returning pulse? You may need to repeat this several times.

12. Repeat the last step by sending a transverse pulse down the left side of the spring. Observe the pulse that returns. On which side of the spring is the returning pulse?

13. Where is the boundary between the two media?

14. What is the second medium in this investigation?

15. Do you think that any of the waves' energy was transferred into the second medium? Support your answer.

Conclusions

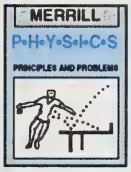
16. Based on your observations, how do waves reflect from the boundary of a less dense medium?

Check your answers by turning to the Appendix, Section 2: Activity 1.

Interpretation of Results

In this investigation the string is too flimsy to exert very much force on the coils of the spring. The pulse simply overshoots its original amplitude when it encounters the string and reflects as an upright pulse (on the same side as the incident pulse).

The last two investigations focused on the extreme case of one medium having a very different density than another. What do you think happens to a wave when it encounters a medium with only a slightly different density? Would a reflection still occur? If a reflected wave does occur, will it be upright or inverted?

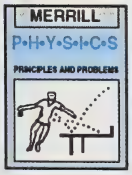


The answers to these questions can be found in your textbook. Carefully read from the bottom of page 294 to the bottom of page 296. Be sure to pay close attention to the diagrams.

17. What is a transmitted wave?

18. Under what circumstances will most of the wave be transmitted?

19. A wave passes most of its energy from medium 1 to medium 2. However, part of the energy is reflected back into medium 1 as an inverted wave. Compare the density of medium 1 to the density of medium 2.



20. Carefully examine Figure 14-9 on page 295 of your textbook. Which spring has the greatest density? Explain your answer.

21. The following diagram shows two springs joined together. Since the springs are attached, the tension is the same in both, but the spring on the left has less massive coils which are much further apart than those on the right.

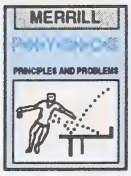
a. Label the boundary on the diagram.

b. Which spring will pass waves with greater speed? Explain your answer.

c. If a wave was generated by shaking one end of the spring, how would the frequencies in the springs compare to each other?

d. How would the wavelengths in the springs compare to each other?

Check your answers by turning to the Appendix, Section 2: Activity 1.



22. Do Practice Problems 5, 6, 7, and 8 on pages 296 and 297 of your textbook.

Check your answers by turning to page 676 of your textbook.

one-dimensional – along a straight line

two-dimensional – occurring on a flat surface

In this activity you have seen how waves behave when they encounter boundaries in springs and ropes. These one-dimensional cases provide a good starting point for the study of wave motion.

In the next activity you will examine the behaviour of two-dimensional waves.

Activity 2: Reflection, Refraction, and Diffraction

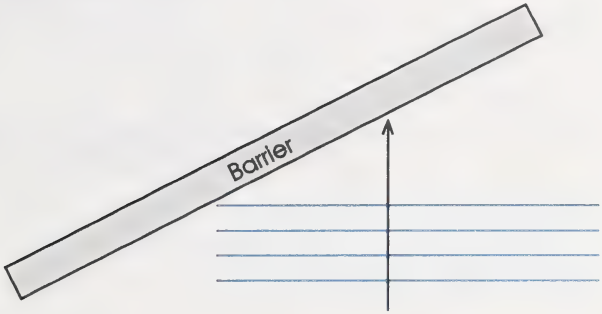
Reflection

What happens when water waves encounter a boundary? How do you think waves will travel after they strike a barrier? Is there a way to describe the direction of the waves before and after they strike a barrier?

Read page 299 of your textbook. Be sure to examine the diagrams at the top of page 299.

1. Define the terms *incident wave ray*, *reflected wave ray*, and *normal*.

2. Use a protractor to draw and label the incident wave ray, the reflected wave ray, and the normal on the following diagram.



3. What idea could you use to check the accuracy of your drawing?

Check your answers by turning to the Appendix, Section 2: Activity 2.

When you looked at the photograph given in the textbook, you probably noticed that the actual waves are not as clear (in terms of their shape and direction) as those in the diagram drawn to the side. The photograph shows that the wave fronts become more irregular and less pronounced as they travel out from the source. By the time the waves become reflected wave fronts, they are so faint that you may have to look very closely to even see them. The diagram helps because it represents an average of the behavior of the waves.

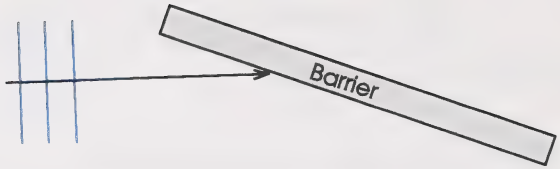
In reality it is very difficult to produce water waves that form long straight wave fronts. If you have access to laboratory facilities, you may enjoy trying to make these patterns in a ripple tank. The advantage of studying water waves in a ripple tank is that the wavelength, frequency, and velocity can all be directly observed, even if the direction of the waves requires some interpretation.

Light rays provide the best way to collect detailed data about the direction of waves. You'll have an opportunity to verify this as you complete investigations in the next two modules.

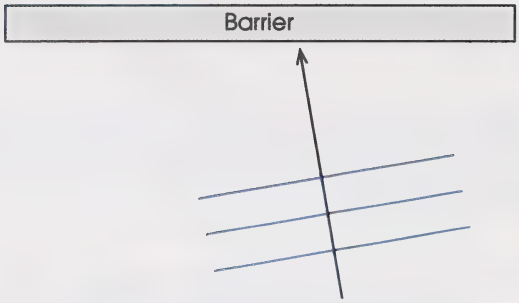
By using a protractor and the law of reflection, it is possible to predict how waves will behave at barriers.

4. The following diagrams show waves in three different circumstances. Use a protractor to complete each diagram. Draw the normal and measure and label the angle of incidence and the angle of reflection.

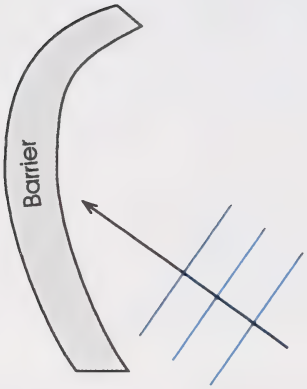
a.



b.



c.



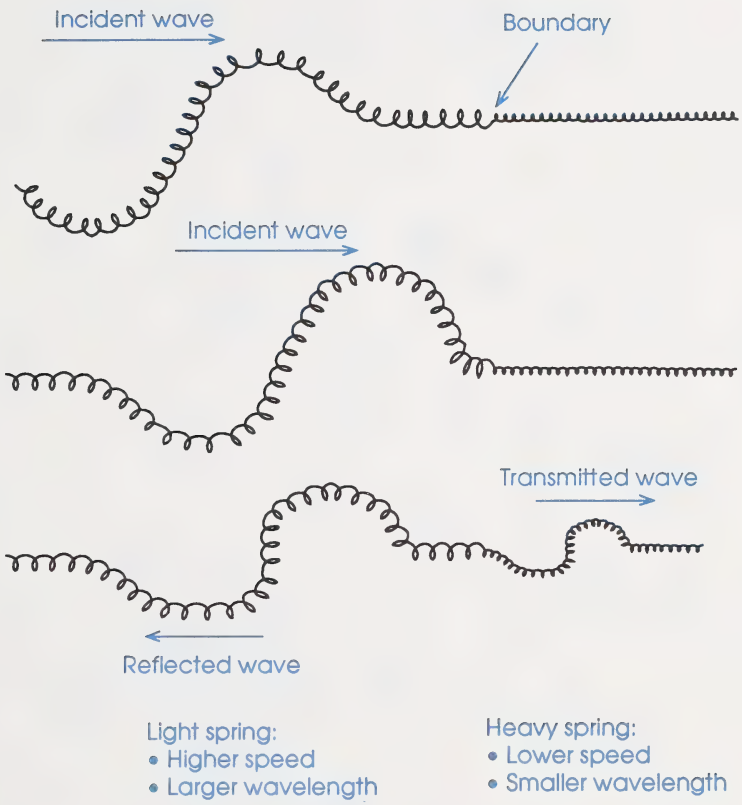
5. Angles are always measured between the wave ray and the normal, not between the wave ray and the barrier. Use your answer from question 4. c. to explain why angles are always measured from the normal.

Check your answers by turning to the Appendix, Section 2: Activity 2.

Refraction

When a wave encounters a place where the medium suddenly changes, some of the wave energy is reflected and some is transmitted. Since the speed of any wave depends on the medium, the transmitted wave will have a different speed than the original wave.

The following diagrams show a wave passing from a light spring to a heavy spring.

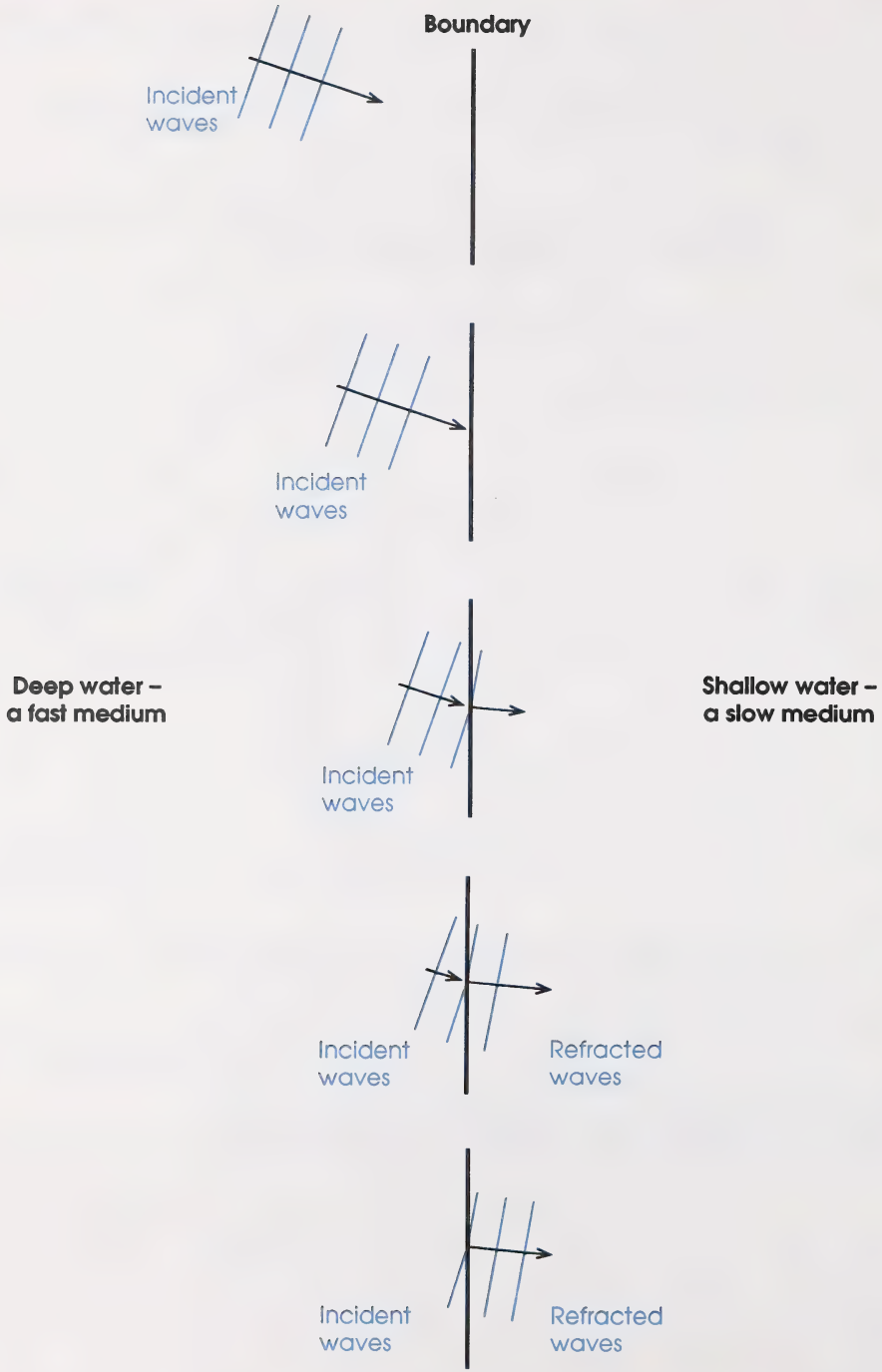


6. Suppose the incident wave has a frequency of 3.6 Hz. What is the frequency of the transmitted wave?

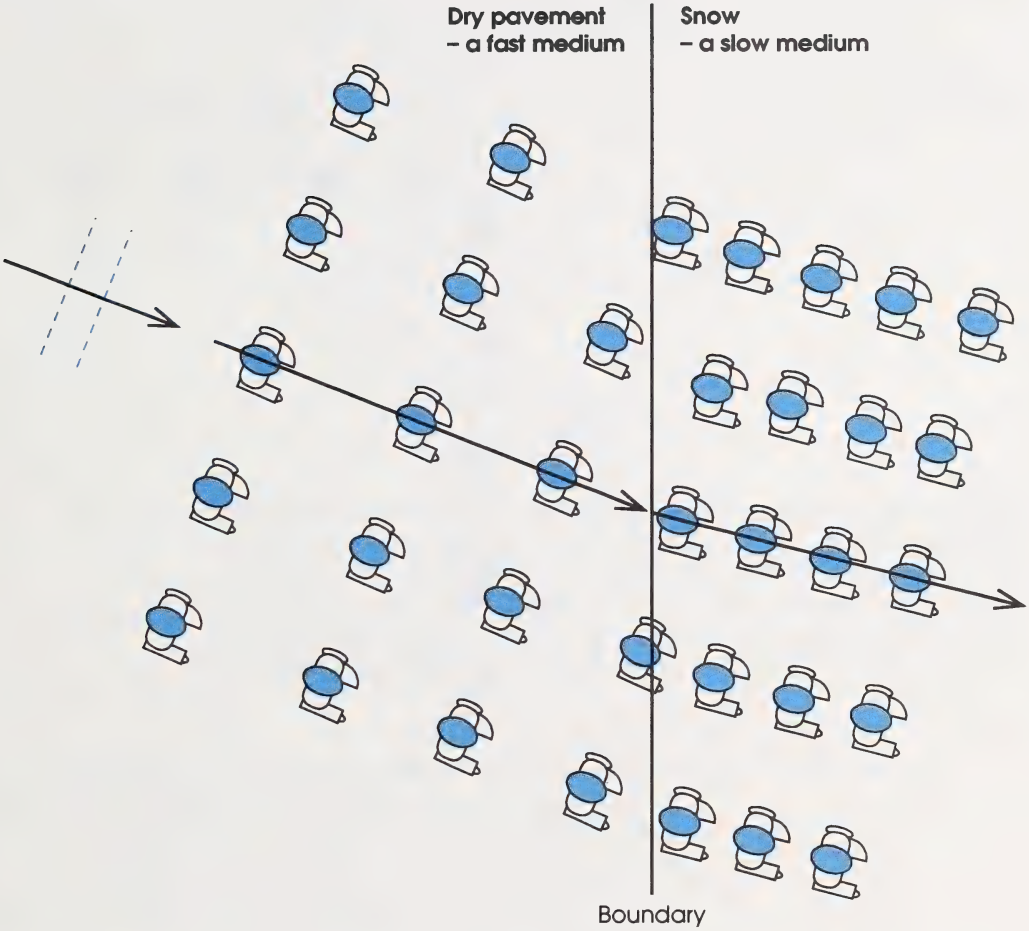
7. If the incident wave and transmitted wave had speeds of 4.8 m/s and 2.4 m/s respectively, calculate the wavelength of each wave.

Water waves behave similar to waves in springs when they encounter changes in depth. Deep water acts like a fast medium, while shallow water acts like a slow medium. However, unlike waves on springs, the part of the water wave which is transmitted may move in a different direction than the incident wave. The change in direction of a two- or three-dimensional wave is known as **refraction**. Refraction is due to the difference in speed between two media. The following diagrams show water waves refracting as they pass from deep water to shallow water.

refraction – a change in the direction of a wave due to a change in speed between two media

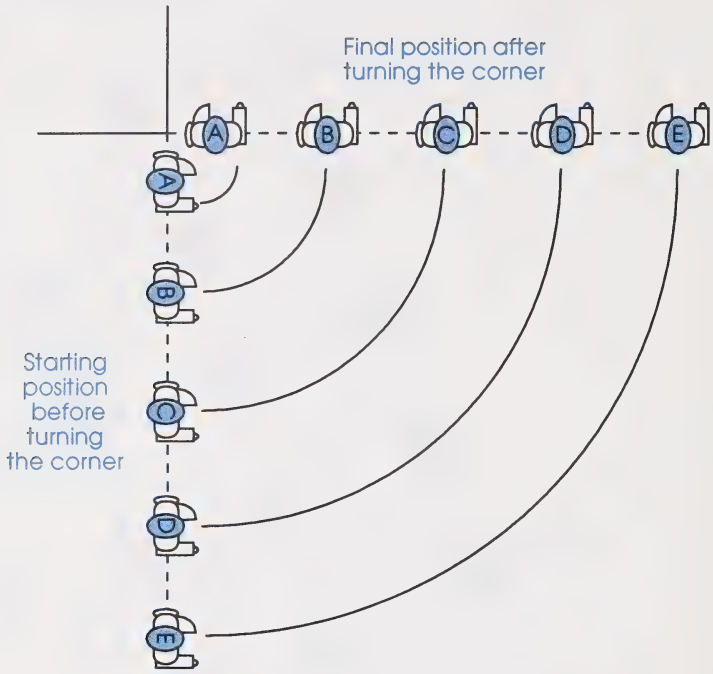

Boundary
Incident waves
Incident waves
Deep water – a fast medium
Shallow water – a slow medium
Incident waves
Incident waves
Refracted waves
Incident waves
Refracted waves

A marching band which is practising on dry pavement may exhibit refraction when it suddenly encounters knee-deep snow. The following diagram helps to illustrate this idea.



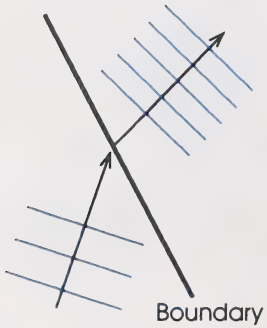
When the members of the marching band reach the snow, they are forced to travel slower. Since they are travelling at a reduced speed, the marchers in each column bunch together. This can be noted by comparing the spacing between the marchers in the snow to the spacing between the marchers on the dry pavement. Not only are the columns affected, but the rows change, too. Since the marchers travel slower when they reach the snow, they fall behind the other members in the same row who are still on the dry pavement. The result is that the whole row of marchers changes direction when it encounters the snow. The idea of one side of an object travelling slower while the other end travels faster to produce turning is also used by bulldozers and tanks.

8. Imagine that you are given the job of teaching a row of people in a marching band how to turn a corner while staying in a straight row. Write concise instructions for band members A to E so that they properly turn the corner.

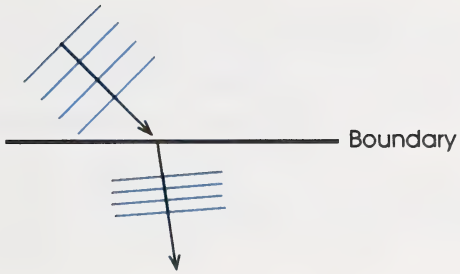


9. The following diagrams show water waves passing from deep water to shallow water. Label each side of the boundary as being either **deep** or **shallow**. Remember that deep water is a fast medium and shallow water is a slow medium. (Hint: Imagine that the incident wave is made up of rows of marchers instead of rows of crests. Would the first marchers who hit the boundary have to speed up or slow down to move in the new direction?)

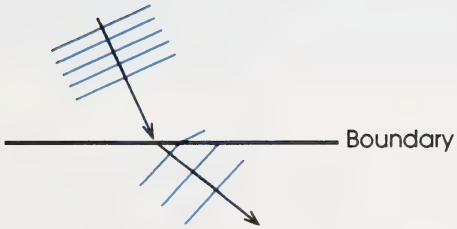
a.



b.

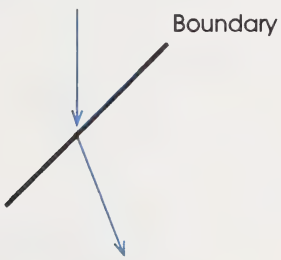


c.

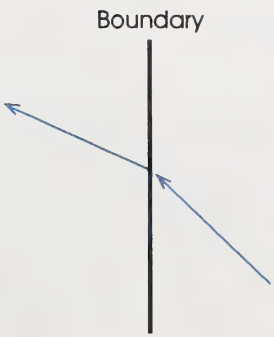


10. The following diagrams show the wave rays for water waves. Label the sides of each boundary either **deep** or **shallow**. Since the wave crests are not shown, you may find it helpful to lay your pencil along the wave ray and slide it towards the boundary. Ask yourself whether the part of your pencil that first crosses the boundary must speed up or slow down to produce the refracted ray shown.

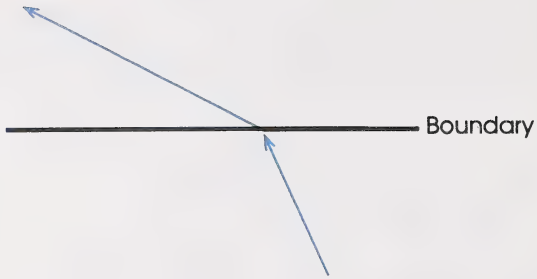
a.



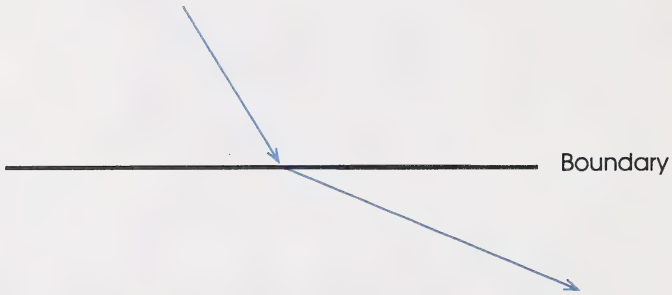
b.



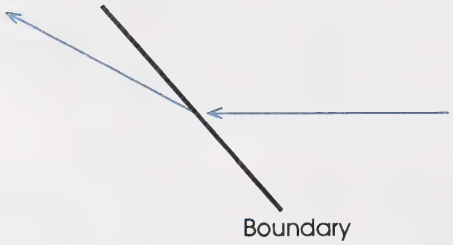
c.



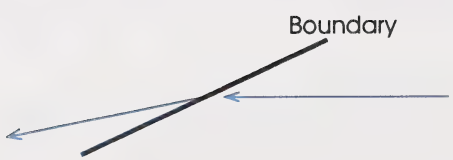
d.



e.



f.



11. Use a protractor to draw a normal on each of the previous diagrams. Label the angle between the wave ray and the normal on the deep water side as θ_{deep}. Label the angle between the wave ray and the normal on the shallow water side as $\theta_{shallow}$.

12. Compare the size of θ_{deep} to $\theta_{shallow}$ in each diagram that you labelled in questions 10 and 11. State a rule about which medium will have larger angles to the normal.

Check your answers by turning to the Appendix, Section 2: Activity 2.

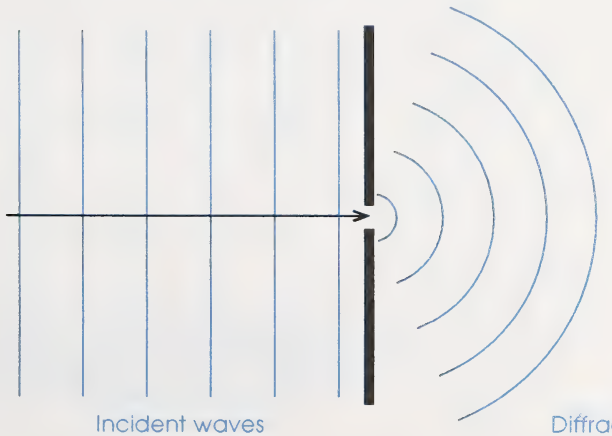
Diffraction

So far you have been assuming that the entire wave strikes the boundary. However, there are occasions when a wave strikes a boundary that has a hole in it or the wave hits a boundary at its edge. In these cases, the part of the wave that passes through the boundary will develop a more circular shape as it spreads out and travels into the region behind the boundary. This behaviour of waves is known as **diffraction**.

diffraction – the spreading of waves as they pass through an opening or past the edge of a boundary

The following diagrams illustrate water waves diffracting through an opening between two boards.

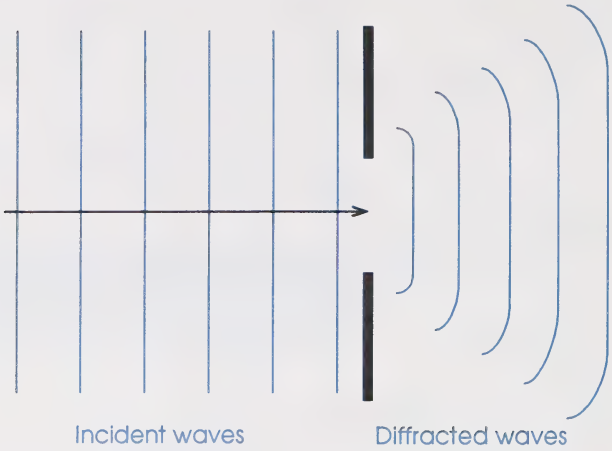
The wavelength is larger than the opening.



Incident waves

Diffracted waves

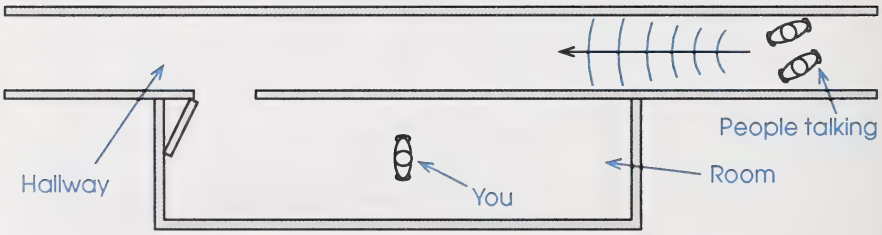
The wavelength is smaller than the opening.



13. Under what circumstance is the diffraction of waves the most pronounced? Study the preceding diagrams when thinking about your answer.

Sound waves also diffract through openings and around obstacles if the conditions are right.

14. Imagine that you are sitting in the room shown in the following diagram. You can hear the voices of people talking down the hallway. Use your knowledge of diffraction to draw in the rest of the sound waves to show how you are able to hear the voices.



Check your answers by turning to the Appendix, Section 2: Activity 2.

PATHWAYS

If you have access to the video entitled *The Properties of Waves (Non-Light)*, do Part A. If you do not have access to the video, do Part B.

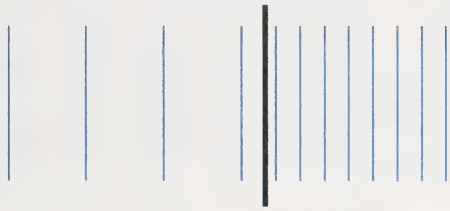
Part A

You already watched the first part of this video in Section 1 of this module. You will now resume watching from where you left off. If necessary, fast forward the video from the beginning until you come to the section of the video called Refraction. You will see examples of refraction, reflection, and diffraction of water waves. This will help you review the main ideas studied so far in this section. You will also be introduced to the concepts of superposition, interference, and standing waves. These concepts will be studied in detail in the next activity.

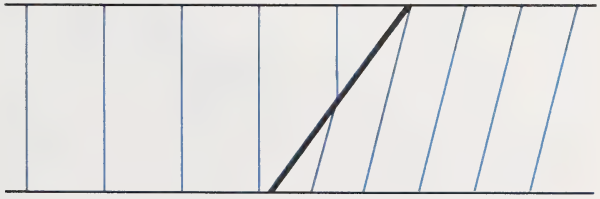
Read through questions 15 to 27 before you watch the video and then answer them as you watch the video.

Refraction

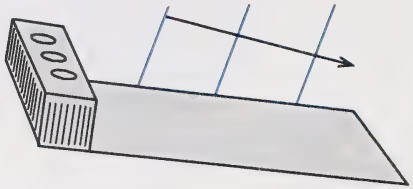
15. The following scene is shown on the video. Label the deep water waves and the shallow water waves.



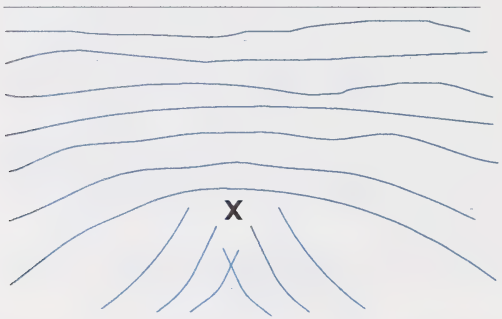
16. The following scene is shown on the video. Label the incident waves, the refracted waves, and the boundary.



17. The video shows water waves encountering shallow water on top of a board. Draw the refracted waves as they pass over the board.



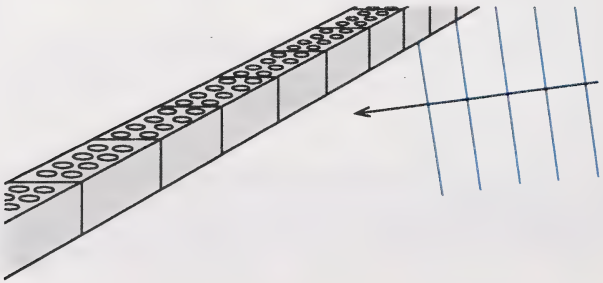
18. Water waves are observed to make the following pattern. What can you conclude about the region identified with the X? Explain your answer.



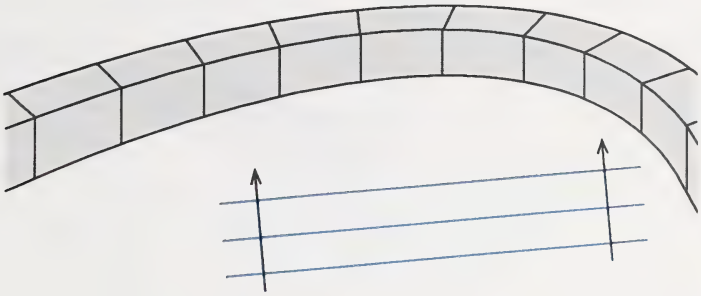
Reflection

19. When a series of water waves approaches a wall of bricks, do the reflected waves prevent other incoming waves from passing?

20. The video shows water waves approaching a row of bricks. Sketch in the reflected waves and the reflected wave ray.



21. The video shows water waves approaching a curved row of bricks. Sketch in the pattern of the reflected waves.



Superposition

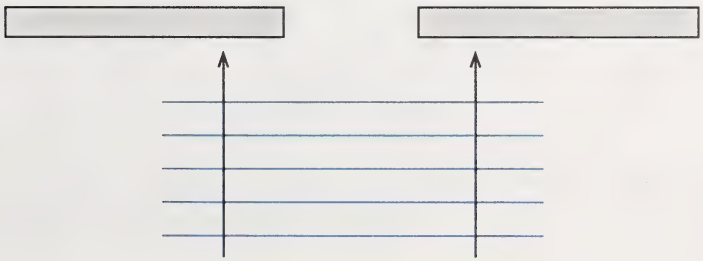
22. What happens when two water waves meet in such a way that a crest passes through a crest?

23. What happens when two water waves meet in such a way that a crest passes through a trough?

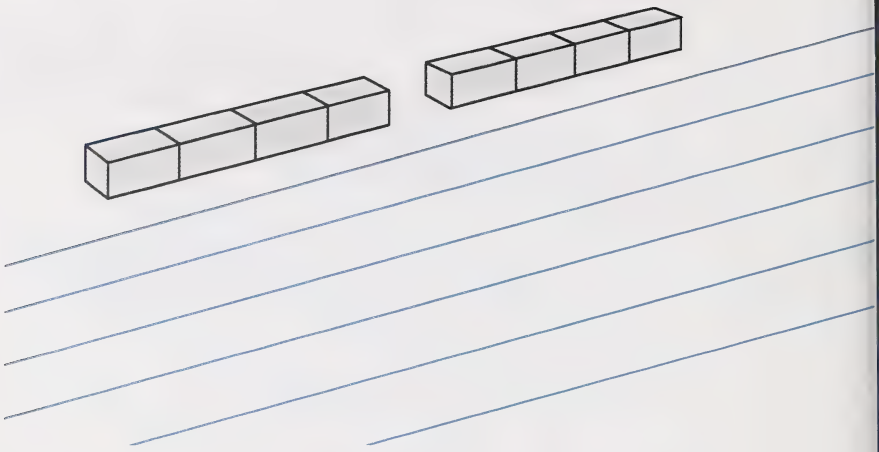
Diffraction

24. If each point along the front of a wave makes circular waves, why do you see another straight wave being created? What happens to all the circles?

25. The video shows straight waves approaching a gap in a barrier. Draw the pattern made by the waves after passing through the gap.



26. The video shows straight wave fronts approaching a barrier of bricks. Draw the pattern made by the waves after passing the barrier.



Standing Waves

27. Why is a standing wave given its name?

End of Part A

Part B

In this part of the activity you will have an opportunity to apply the concepts of refraction, reflection, and diffraction to a number of interesting situations.

In each case you will be presented with a real-life circumstance that requires you to apply the main ideas from this section. In each case it is the diagram that deserves your greatest attention. If you are having trouble solving one of the problems, you may want to glance at only the diagram provided in the Appendix as an initial hint. Then you may have gained enough insight to solve the rest of the problem.

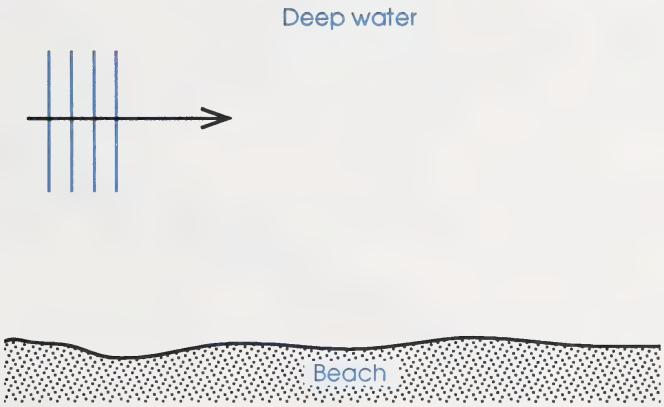
The ideas presented in these questions are important because they form the foundation of your study of light in the next two modules. Not only will the strategy of using diagrams make problem solving more interesting, it will also help you understand the basic physics.

28. If you've ever been to a beach, you may have noticed that waves always come in with their crests parallel to the beach, no matter what direction

the waves travel in off-shore. Assume that the water is shallower close to the shore.

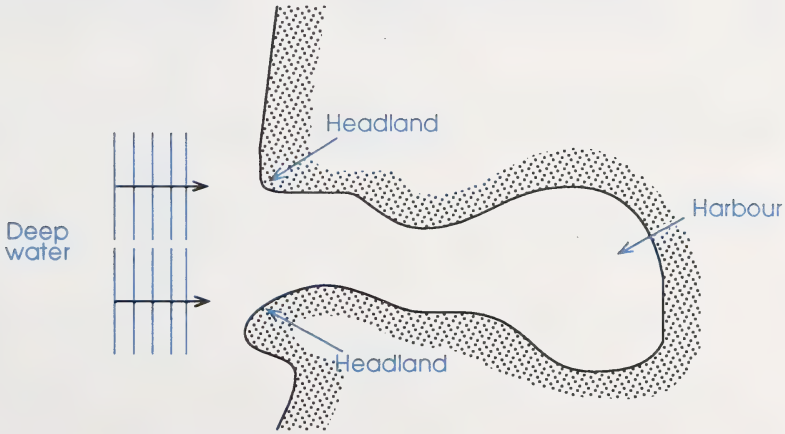
a. Explain what causes the waves to turn towards the beach.

b. Complete the following diagram by drawing the path of the waves to the beach.



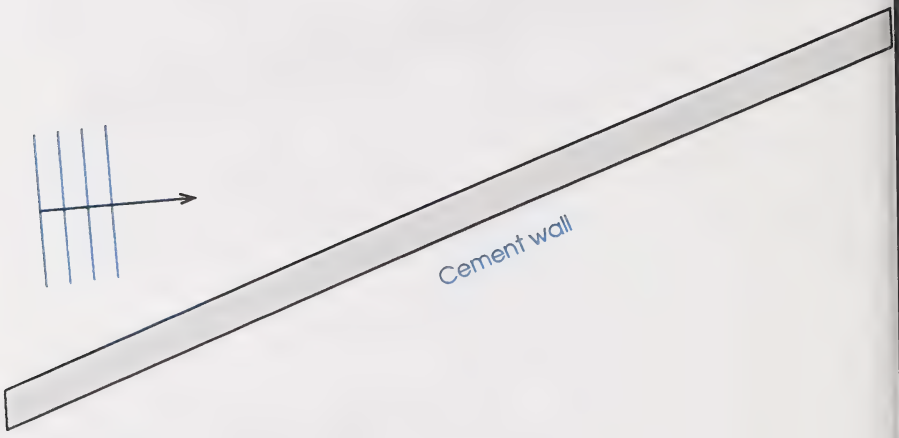
29. Fishermen know that the best way to protect their boats from being smashed on the rocks by powerful ocean waves is to anchor them in a harbour.

a. Assume that the water gradually becomes shallower towards the shore. Complete the following diagram by drawing the path of each set of waves.

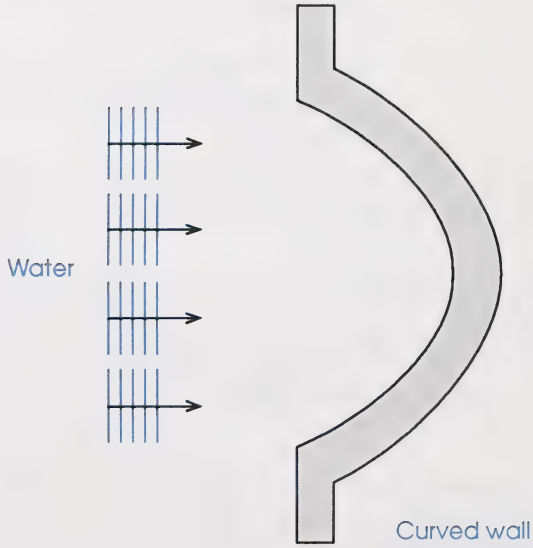


b. The points on either side of the mouth of the harbour are called the headlands. Explain why the headlands tend to get hit the hardest by the waves.

30. The following diagram shows a group of water waves about to strike a cement wall. Extend the incident wave ray to the wall, draw the normal, and then draw the reflected wave ray according to the law of reflection. Use a protractor to properly measure the angles of incidence and reflection.



31. The following diagram shows four groups of water waves moving towards a curved wall.



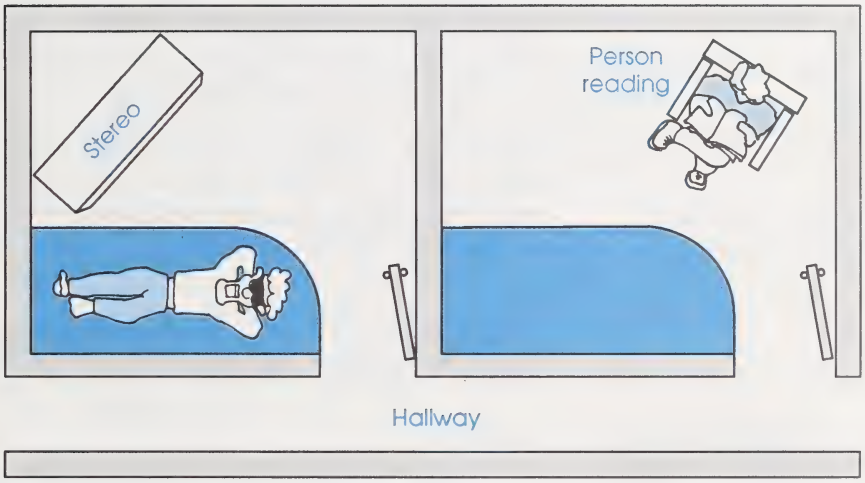
a. For each group of waves, extend the incident wave ray to the wall, draw the normal, and then draw the reflected wave ray according to the law of reflection.

b. Look up the terms *focus* and *focal point* in a dictionary. Label the focal point on the diagram.

c. The diagram could also represent microwaves being reflected to a satellite dish. Explain the function of a satellite dish.

32. Imagine that you are trying to study in your bedroom with the door open. Sounds from the hallway start to distract you, so you close the door most of the way. You find that it is almost as noisy as before, so you close the door completely. Now it is much quieter. Draw a diagram to explain why so many sound waves still entered your room when the door was open only a few centimetres.

33. The following diagram shows two rooms with doors that open into a common hallway. A person is listening to music in one room and someone is reading in the other room.



a. Explain why the low-pitched (long wavelength) sounds from the stereo can travel down the hallway and into the other room. Use a 100-Hz sound to help explain your answer.

b. Draw the path of low-pitched sound waves on the diagram.

c. Explain why the very high-pitched (small wavelength) sounds from the stereo can only be heard in the hallway if you stand directly in front of the open door of the room with the stereo. Use a 10 000-Hz sound to help explain your answer.

d. Draw the path of the very high-pitched sound waves on the diagram.

Check your answers by turning to the Appendix, Section 2: Activity 2.

End of Part B

In the next activity you will continue your study of the behaviour of waves by investigating what occurs when two waves overlap.

Activity 3: Interference

Imagine two friends at opposite ends of a hallway. Both people are speaking and are therefore sending out sound waves. Do the words bounce off each other in the middle of the hallway so that each speaker hears only his own voice? If you stood between them, what would you hear?

In the next investigation you will examine a similar situation with waves on a spring. What do you think happens when two pulses travelling towards each other in the same spring meet? Do the pulses bounce off each other or do they pass through each other?

Investigation: What Happens When Waves Meet?

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☐ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Purpose

In this investigation you will observe what happens when a crest meets a crest, when a trough meets a trough, and when a crest meets a trough.

Materials

You will need the following materials for this investigation:

- a long coil spring
- an area of floor space that is about 1 m by 5 m
- a partner

You will need to set up a data chart to show what waves look like before, during, and after they meet. You will need to record data for a crest meeting a crest, a trough meeting a trough, and a crest meeting a trough.

Procedure

- Set up the apparatus as shown in the following diagram.

- This investigation works best if you use only half of the spring. Grasp the coils at the halfway point and let the unused half of the spring lay on the floor.

- The determination of whether a pulse is a crest or a trough is all a matter of your point of view. What you call a crest your partner may call a trough. To keep things straight, adopt the convention that pulses that are on your right are crests, while those on your left are troughs.

- Create a transverse pulse that travels down the right-hand side of the spring. At the same time, have your partner make a pulse that travels down the same side of the spring. Repeat this step several times until you can describe what happens when the pulses overlap.

1. Record your observations on the data chart under the heading Crest Meets Crest.

   - Follow the same procedure as before to create a pulse that travels down the left side of the spring. Have your partner make a pulse that travels down the same side of the spring. Repeat this step several times until you can describe what happens when the pulses overlap.

2. Record your observations on the data chart under the heading Trough Meets Trough.

   - Create a pulse that travels down one side of the spring and have your partner create a pulse that travels down the other side. Repeat this step several times until you are able to describe what happens when the pulses overlap.

3. Record your observations on the data chart under the heading Crest Meets Trough.

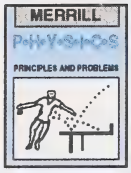
Analysis

4. How could you determine if the pulses bounce off each other or if they travel through each other?

Conclusions

5. Summarize the results presented on the data table by stating one principle that summarizes the results.

Check your answers by turning to the Appendix, Section 2: Activity 3.



To see how your textbook explains what happens when two waves meet, read the section called Superposition of Waves on page 297 of your textbook. Study Figure 14-14 on page 297 and Figure 14-15 on page 298.

6. What is the principle of superposition?

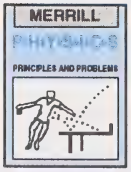
7. Define *constructive interference*. Illustrate your answer with a diagram that clearly shows an antinode.

8. Define *destructive interference*. Illustrate your answer with a diagram that clearly shows a node.

Standing Waves

standing wave – a wave which appears to stand still due to the interference of two identical waves

An interesting application of interference is the creation of a **standing wave**. Although a standing wave appears to be standing still, it is actually an interference effect caused by two waves travelling in opposite directions. You created standing waves in Activity 2 of Section 1.



Carefully read the top paragraph on page 150 in your textbook and the section called Standing Waves on page 298 to learn how standing waves are created.

9. What is mechanical resonance?

10. When you made standing waves in the spring in Activity 2 of Section 1, what provided the small external force at regular time intervals?

11. What factors determine the proper frequency for making a standing wave in the spring?

The most interesting example of standing waves is the use of resonant air columns in musical instruments. This will be examined in Activity 4 of this section.

Two-source Interference Pattern

Another intriguing application of interference occurs when two sources produce the same circular waves quite close to each other. The next investigation will give you an opportunity to explore this concept with sound waves.

Investigation: Interference from a Tuning Fork

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☐ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Purpose

The purpose of this investigation is to observe a two-source interference pattern created by sound waves.

Materials

For this investigation you will need the following materials:

- a tuning fork
- an athletic shoe with a soft sole

Procedure

- Before you make any observations, it is important for you to apply the definitions that you encountered earlier to sound waves.

12. Define the terms *node* and *antinode* as they apply to sound.

- Strike the tuning fork firmly against the sole of the athletic shoe. Then hold the tuning fork about 25 cm from your ear and turn the tuning fork. Listen to the changes in the sound from the tuning fork while it is being turned.

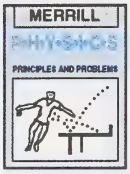
13. Describe the changes in the sound during the first few seconds that the tuning fork is turned.

Analysis

Each tine of the tuning fork is a source of circular sound waves. When these sound waves reach your ear, you hear the resulting interference of the two overlapping circular waves.

14. Sound waves have compressions and rarefactions instead of crests and troughs. Use these terms to describe how a node and an antinode could be formed with sound waves.

A two-source interference pattern can also be formed by water waves. In this case, it is crests and troughs that produce the nodes and antinodes.



Read the top half of page 301 of your textbook to learn how two-source interference patterns can form in water waves.

15. How are nodes created in water waves? What do nodes look like in a ripple tank.

16. How are antinodes created in water waves? What do antinodes look like in a ripple tank?

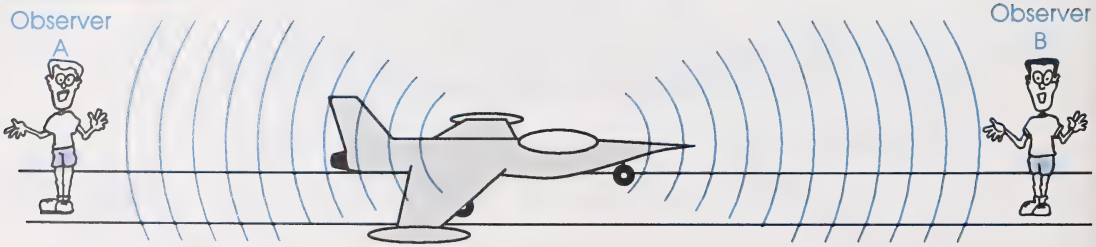
Check your answers by turning to the Appendix, Section 2: Activity 3.

shock wave – a constructive interference effect due to an object travelling faster than the speed of sound

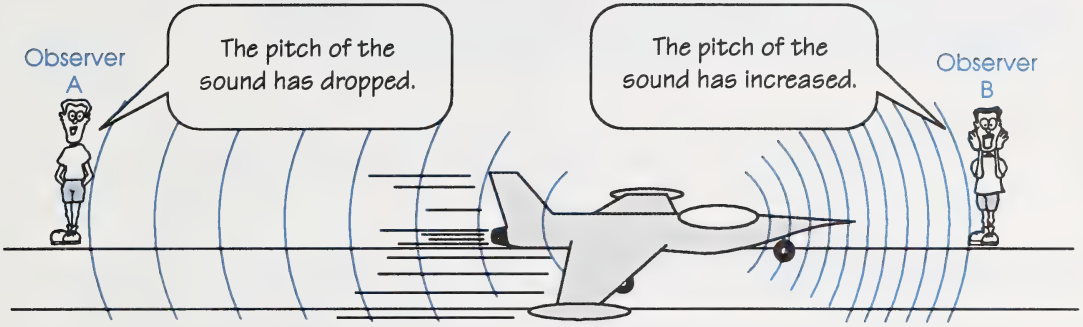
supersonic – able to travel faster than the speed of sound

Another interesting application of interference is the formation of a **shock wave**. The best way to understand the formation of a shock wave is to think of the steps taken by a **supersonic** aircraft preparing to reach its highest speed.

- The aircraft warms up its engines while at rest on the runway. Observers A and B both hear the same sound from the engines.

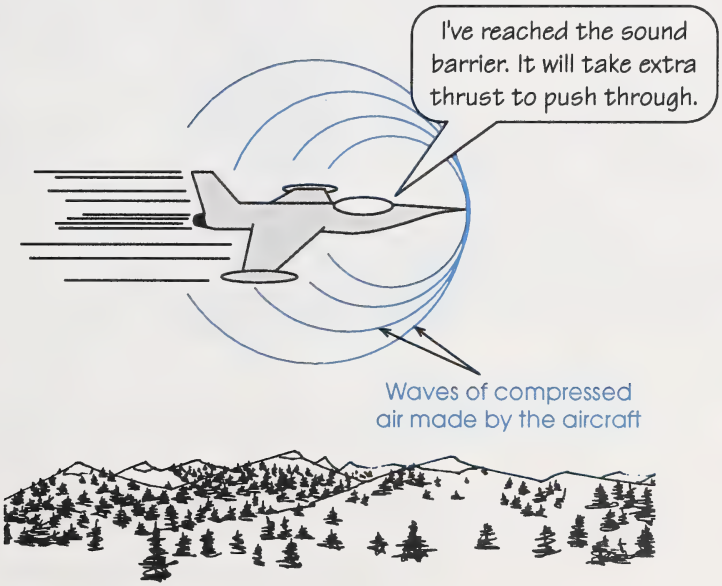


- While taking off, the aircraft travels toward Observer B. The speed of the aircraft is not close to the speed of sound, but the motion of the jet has affected the sound from its engines.

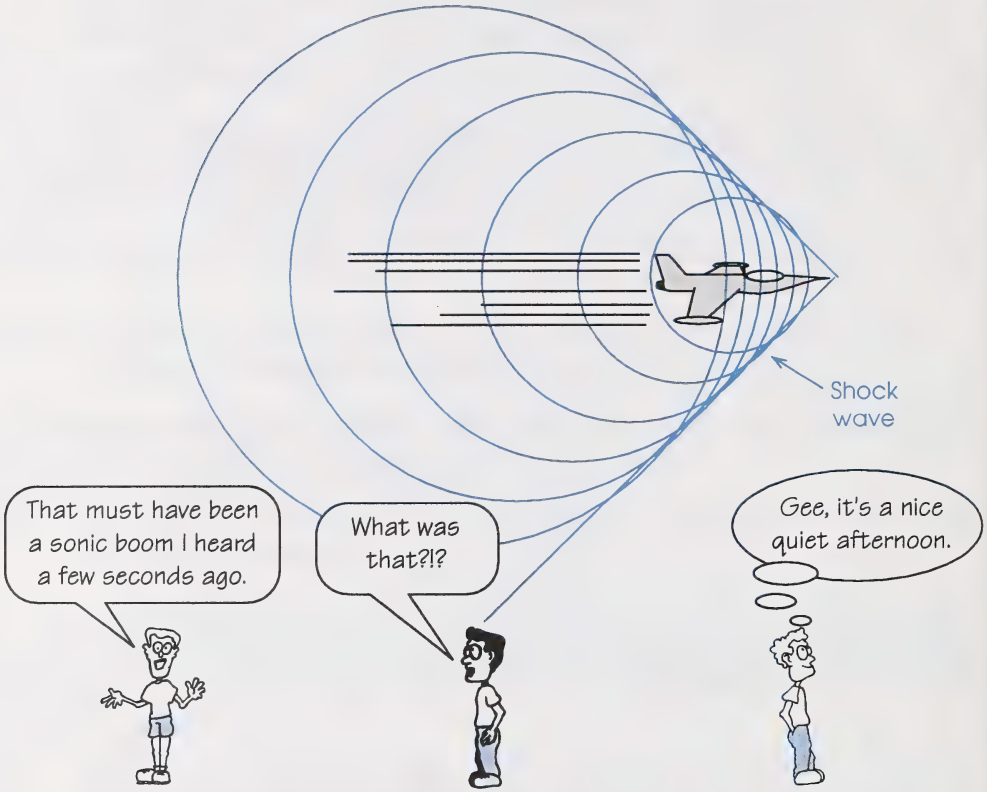


17. Explain why Observers A and B no longer hear the same pitch of sound from the engines once the plane starts moving.

- Once the jet is in the air, it can accelerate until it has reached the speed of sound. At this speed the motion of the jet begins to compress the air in front of it, creating a barrier of high-pressure air. Since the jet is travelling at the same speed as the barrier of compressed air in front of it, it takes extra energy to push through the barrier. No shock wave has been created yet.



- When the jet pushes through the barrier of compressed air, it is travelling supersonically (faster than the speed of sound). As long as the jet travels faster than the speed of sound, it will produce a shock wave. The shock wave results from the constructive interference of the compressions that now follow the aircraft in a cone shape.



sonic boom – the sound from an object travelling at supersonic speeds that is heard by observers

Observer A has already heard the shock wave pass, while Observer B has just had the line of compressions reach his ears. The loud crack just heard by Observer B is called a **sonic boom**. Observer C will hear the sonic boom momentarily when the shock wave passes over. The shock wave will continue to follow the plane as long as its speed is supersonic.

It is not the sound of the aircraft's engine that creates the shock wave. The shock wave is made by the waves of compressed air that are pushed out of the way by the aircraft. A bullet and the end of a whip can both create a shock wave if they travel faster than the speed of sound.

18. Why would the shock wave created by a bullet sound more like a "crack", while the shock wave created by an aircraft is more like a "boom"?

19. Is it true that a sonic boom is produced only at the instant when the aircraft penetrates the sound barrier?

Check your answers by turning to the Appendix, Section 2: Activity 3.

In the next activity you will learn how interference effects can be used to explain the workings of musical instruments.

Activity 4: Musical Sounds

WESTFILE INC.

What is your favourite type of music? If other people were asked the same question, it is unlikely that they would give exactly the same answer that you did. Musical tastes can vary so much that what is music to one person may seem like noise to someone else. As you complete the rest of this activity, the following criteria will be used to distinguish between music and noise.

Music	Noise
• The sounds are pleasing to the listener's ear. • The sound waves form a regular recurring pattern.	• The sounds are unpleasant to the listener's ear. • The sound waves do not form a regular recurring pattern.

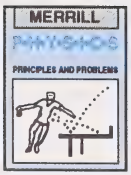
1. Whether a sound is musical can be determined by analysing the sound for wave patterns, but the listeners still need to decide if what they hear is truly music. Explain.

It is worthwhile to note a few more things about noise before doing a detailed study of musical sounds. The frequencies that make up noise sound unpleasant simply because there are so many of them. While music contains only certain frequencies that combine to form a pleasing sound to the listener's ear, noise contains many frequencies that bear little relation to one another.

Noise can be a health hazard if the sound level (measured in decibels) is too high. The result can be a partial or complete loss of hearing. Factory workers need to wear special ear protection to protect them from dangerously high noise levels in their work environment. People that live near busy freeways or airports also need to be protected from annoying or dangerous noise levels. Protection from freeway noise is easier to provide than aircraft noise protection. Protection from the noise emitted by jet aircraft is a more difficult matter because of the higher noise level emitted and because the sound originates from above you. The most common strategy is to make sure that new airports are built beyond the outskirts of the city, reducing the number of people that are subjected to the high noise levels.

Resonance in Open and Closed Pipes

All musical instruments use standing waves and resonance to make the music loud enough to be heard. In many cases the resonance is set up by a column of air which increases the loudness of certain frequencies. Before learning more about the workings of musical instruments, it is worthwhile to stop and take a close look at standing waves within an air column.

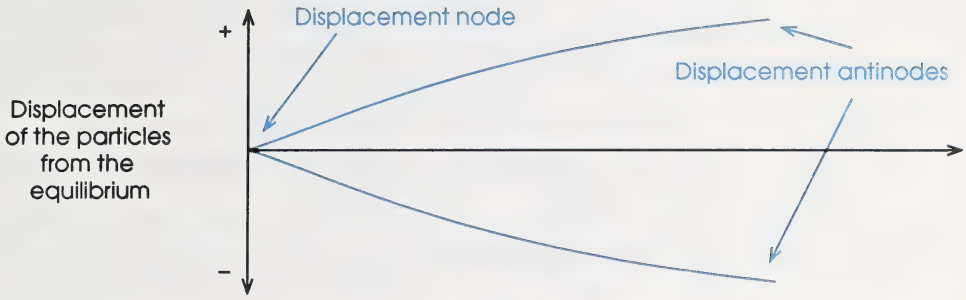


Read the section called Resonance which is found on pages 315 to 318 of your textbook. Be sure to study all the diagrams that are referenced in the reading.

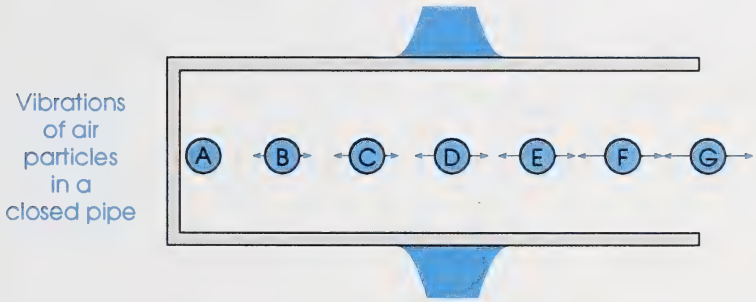
It is important to have a clear understanding of the graphs of the standing waves that are shown on pages 316, 317, and 318 of your textbook. Carefully

examine the diagrams on this page. In the centre of the diagram, air particles are represented by the circles within the closed pipe. The particles have been labelled A through G so that they can be referred to easily. The diagram is not drawn to scale.

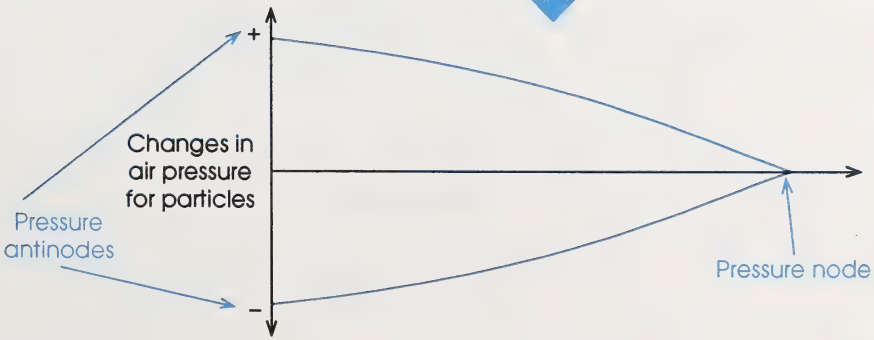
There are two ways to represent the standing wave of a resonant air column in a pipe.



Representing the standing wave in terms of displacement



Representing the standing wave in terms of pressure



If you consider the actual motion of the particles in the pipe (top diagram), particle A is a node because it can't vibrate back and forth due to the end of the pipe. Particle G is an antinode because it has the most freedom to vibrate in and out of the end of the pipe. Thinking about the displacement of the particles from equilibrium is one way to represent a standing wave in a pipe.

Another approach is to think of the changes in air pressure within the pipe. In this case, particle A is a pressure antinode because it has nowhere to go and can be either pushed or pulled away from the closed end of the pipe. Particle G is a pressure node because of the free air at the open end of the pipe. Particle G cannot be put under pressure because there is nothing other than the atmosphere to hold it in place.

2. Which approach is used by the textbook to explain standing waves in pipes?

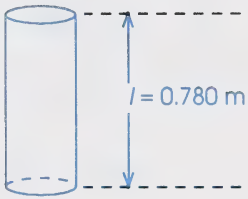
3. Why does a pipe that is open at both ends have a pressure node at each end?

Open Pipes

fundamental frequency – the lowest frequency that makes up a sound

The lowest frequency that can be created by a resonant air column is called the **fundamental frequency**. The following example shows how to calculate the fundamental frequency for an open pipe that is 0.780 m long.

Example



- For this open pipe, the fundamental frequency occurs because the pipe is half of a wavelength long. The subscript 1 is used to denote the wavelength of the fundamental frequency.

$$\begin{aligned}\frac{1}{2}\lambda_1 &= l\\ \lambda_1 &= 2l\\ &= 2(0.780\text{ m})\\ &= 1.56\text{ m}\end{aligned}$$

- The fundamental frequency can be calculated from the speed of sound using the universal wave equation.

$$\lambda_1 = 1.56 \text{ m}$$
$$v = 343 \text{ m/s}$$
$$f_1 = ?$$

$$v = \lambda_1 f_1$$
$$f_1 = \frac{v}{\lambda_1}$$
$$= \frac{343 \text{ m/s}}{1.56 \text{ m}}$$
$$= 220 \text{ Hz}$$

overtones – higher frequencies that are created in addition to the fundamental frequency

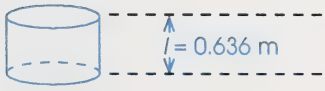
harmonics – overtones which are exact multiples of the fundamental frequency

This is not the only frequency that could be created by this pipe. As you learned in the last section, **overtones** can also be created. Overtones are responsible for the quality of the sound that is produced. When the overtones are exact multiples of the fundamental frequency, they are called **harmonics**. The following chart shows the first five harmonics for the open pipe analysed in the example.

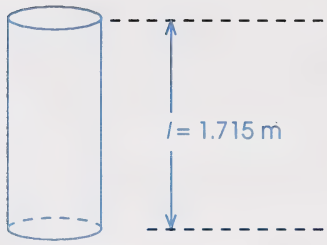
	Harmonic	Symbol	Frequency
Fundamental Frequency	First harmonic	f_1	$f_1 = 220$ Hz
Overtones	Second harmonic	f_2	$f_2 = 2f_1 = 2(220 \text{ Hz}) = 440$ Hz
	Third harmonic	f_3	$f_3 = 3f_1 = 3(220 \text{ Hz}) = 660$ Hz
	Fourth harmonic	f_4	$f_4 = 4f_1 = 4(220 \text{ Hz}) = 880$ Hz
	Fifth harmonic	f_5	$f_5 = 5f_1 = 5(220 \text{ Hz}) = 1100$ Hz

4. Calculate the fundamental frequency and the first three overtones for the following open pipes. Consider the speed of sound to be 343 m/s.

a.



b.



5. The lowest frequency sound that humans can hear is 20 Hz. What length of open pipe would produce this sound as its fundamental frequency?

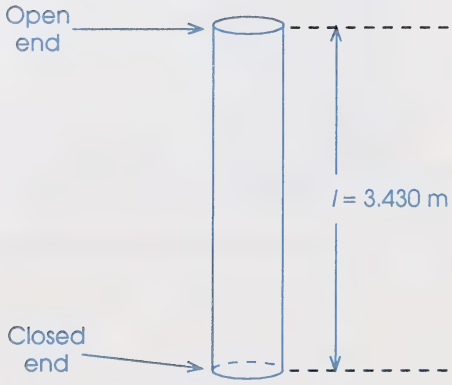
6. The highest frequency sound that humans can hear is 20 000 Hz. What length of open pipe would produce this sound as its second harmonic?

Check your answers by turning to the Appendix, Section 2: Activity 4.

Pipes that Are Closed at One End

Although the terminology is the same for pipes that are closed at one end, there are some important differences between the sounds produced by closed pipes and open pipes. The following example shows how to calculate the fundamental frequency and harmonics for a closed pipe that is 3.430 m long.

Example



- For a closed pipe, the fundamental frequency occurs because the length of the pipe is one-quarter of a wavelength long.

$$\begin{aligned}\frac{1}{4}\lambda_1 &= l\\ \lambda_1 &= 4l\\ &= 4(3.430\text{ m})\\ &= 13.72\text{ m}\end{aligned}$$

- The fundamental frequency can be calculated from the speed of sound using the universal wave equation.

$$\begin{aligned}\lambda_1 &= 13.72\text{ m}\\ v &= 343\text{ m/s (Assuming the air column is at 20°C.)}\\ f_1 &= ?\end{aligned}$$

$$\begin{aligned}v &= \lambda_1 f_1\\ f_1 &= \frac{v}{\lambda_1}\\ &= \frac{343\text{ m/s}}{13.72\text{ m}}\\ &= 25.0\text{ Hz}\end{aligned}$$

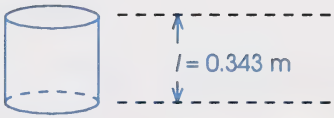
- The following chart shows the first five harmonics for the pipe analysed in the example.

	Harmonic	Symbol	Frequency
Fundamental Frequency	First harmonic	f_1	25.0 Hz
Overtones	Third harmonic	f_3	$f_3 = 3f_1 = 3(25.0\text{ Hz}) = 75.0\text{ Hz}$
	Fifth harmonic	f_5	$f_5 = 5f_1 = 5(25.0\text{ Hz}) = 125\text{ Hz}$
	Seventh harmonic	f_7	$f_7 = 7f_1 = 7(25.0\text{ Hz}) = 175\text{ Hz}$
	Ninth harmonic	f_9	$f_9 = 9f_1 = 9(25.0\text{ Hz}) = 225\text{ Hz}$

- Note that only the odd-numbered harmonics are present in a closed pipe. This is due to the fact that there must always be an antinode at one end of the pipe and a node at the other end of the pipe, as shown in Figure 15-10 on page 317 of your textbook.

7. Calculate the fundamental frequency and the first three overtones for the following closed pipes. Consider the speed of sound to be 343 m/s.

a.



b.

The auditory canal of the human ear can be considered a closed pipe resonator. Turn to page 319 of your textbook and examine Figure 15-12.

8. If the auditory canal of the ear is 3.0 cm long, what frequency of sound would resonate as the fundamental frequency of the ear?

9. Earlier in this module, while studying the threshold of hearing, you learned that people are most sensitive to sounds slightly below 3000 Hz. Re-interpret this fact by reconsidering your answer to the previous question.

Check your answers by turning to the Appendix, Section 2: Activity 4.

10. To see how the physics of resonating air columns can be applied, do Practice Problems 5, 6, 9, and 10 on page 318 of your textbook.

Check your answers by turning to pages 676 and 677 in your textbook.

In the previous questions you used the speed of sound to calculate the wavelengths and frequencies of resonant sounds in open and closed pipes. It is also possible to reverse this process and use the resonant frequencies to calculate the speed of sound.

Investigation: Measuring the Speed of Sound

Science Skills

- ☑ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☑ F. Evaluating

Purpose

In this investigation you will use a closed resonant air column to obtain an experimental value for the speed of sound in air that is at room temperature (20°C).

Materials

The following materials are recommended for this investigation:

- a tuning fork with a known frequency
- a deep bucket filled with water
- a length of plastic pipe or tubing
- a metre stick
- a rubber mallet or soft-soled athletic shoe

Procedure

11. Design an experiment that will enable you to calculate a value for the speed of sound and then carry out the experiment. Be sure to record all measurements on a data chart. Analyse the data to obtain an experimental value for the speed of sound at 20°C. Remember to calculate a percent error and to list possible sources of error in your data.

Check your answers by turning to the Appendix, Section 2: Activity 4.

All the topics of this module can be combined to produce a better understanding of the physics of music. Many students find this to be a fascinating way to apply the main ideas from their study of waves and sound.

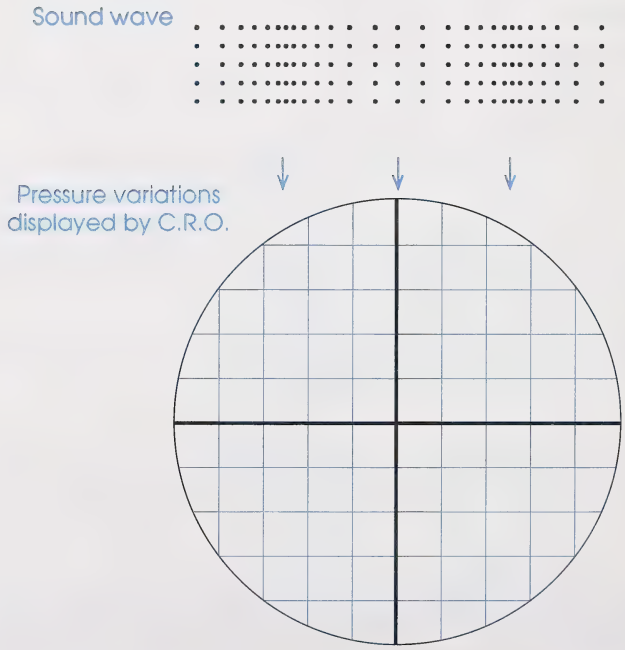
PATHWAYS

If you have access to the video entitled *The Physics of Music*, do Part A. If you do not have access to the video, do Part B.

Part A

Prior to watching the video, familiarize yourself with the following questions. Then answer these questions as you watch the video.

12. The diagram that follows shows the compressions and rarefactions of a sound wave. Draw the corresponding pressure variations that would be displayed on the cathode ray oscilloscope.



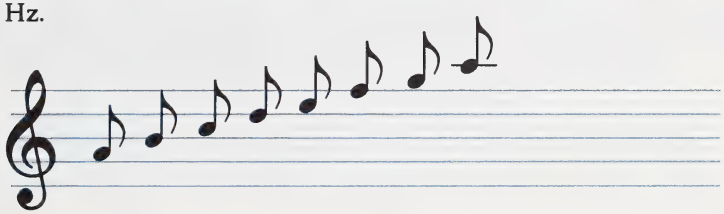
Pitch

13. When explaining pitch, the video displays the pressure variations for four versions of the musical note A. Complete the following chart by writing the frequency for each of the four notes.

	Lowest A	A	A	Highest A
Frequency (Hz)				

14. Add labels to the previous chart to show which notes are separated by exactly one octave.

15. Musicians don't use frequency to identify notes. Instead they use the musical notation shown in the following diagram. Label the note which corresponds to A of 440 Hz and the note which corresponds to A of 880 Hz.



16. How many flutes would have to be played at the same time to sound twice as loud as one flute?

17. How do workers in factories protect themselves from the extremely loud sounds of the equipment?

Quality

18. The video showed the following computer displays of four musical instruments and one human voice all playing or singing the A of 220 Hz. Write the name of the instrument or voice that created the sound displayed by the computer and list a few adjectives to describe the quality of the sound.

    a.

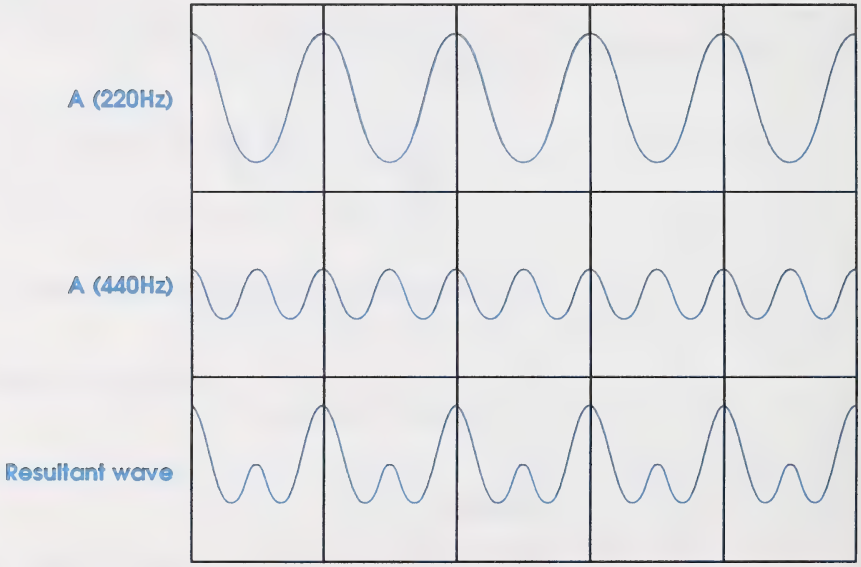
b.

c.

d.

e.

19. The video shows a representation of how a computer would apply the principle of superposition to the note A of 220 Hz and the note A of 440 HZ.



a. Label the points on the resultant wave that best show constructive interference with a C.

b. Label the points on the resultant wave that best show destructive interference with a D.

c. Use a few adjectives to describe the change in quality of the sound as the second A is added to the first.

Musical Instruments

20. List the primary vibrator and resonant vibrator for each of the following musical instruments.

    a. didjeridoo
    b. bassoon
    c. organ
    d. flute
    e. violin
    f. guitar
    g. marimba

21. The following diagram shows a standing wave on a string. Label the node, the antinode, and the place that is best to drive the vibrations on the string.

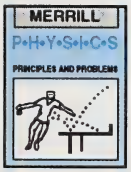
22. Why is it so important to hit a drum head so far off centre?

Check your answers by turning to the Appendix, Section 2: Activity 4.

End of Part A

Part B

Pitch and Loudness



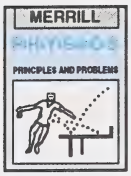
Reread the section called Pitch and Loudness which is found on pages 310 and 311 of your textbook. As you read through it, focus on the description of musical notes.

23. What is an octave? Give two examples to help support your answer.

Read the introduction and the section called Sources of Sound on pages 314 and 315 of your textbook.

24. List the source of vibration for each of these musical instruments.

    a. human voice
    b. trumpet
    c. tuba
    d. clarinet
    e. saxophone
    f. flute
    g. pipe organ
    h. piano
    i. guitar



Read pages 318 and 319 in your textbook.

25. Compare the following forms of ear protection in terms of their ability to reduce the sound level.

Type of Ear Protection	Reduction in Sound Level (dB)
Cotton Ear Plugs	
Special Ear Inserts	
Specially Designed Ear Muffs	

Read pages 320 to 323 in your textbook to learn more about what gives a musical sound its quality.

26. Explain how beats occur by referring to Figure 15-14.

27. How can beats be used to tune an instrument?

28. Define *consonance* and *dissonance*.

29. Do Concept Review questions 2.2 and 2.3 on page 324 of your textbook.

End of Part B

Before doing the Follow-up Activities, you should quickly review the entire module.

30. Quickly review Module 5 to identify the most important equations from this module. Add these equations to your list of equations for the whole course.

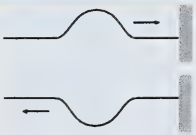
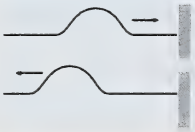
Check your answers by turning to the Appendix, Section 2: Activity 4.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

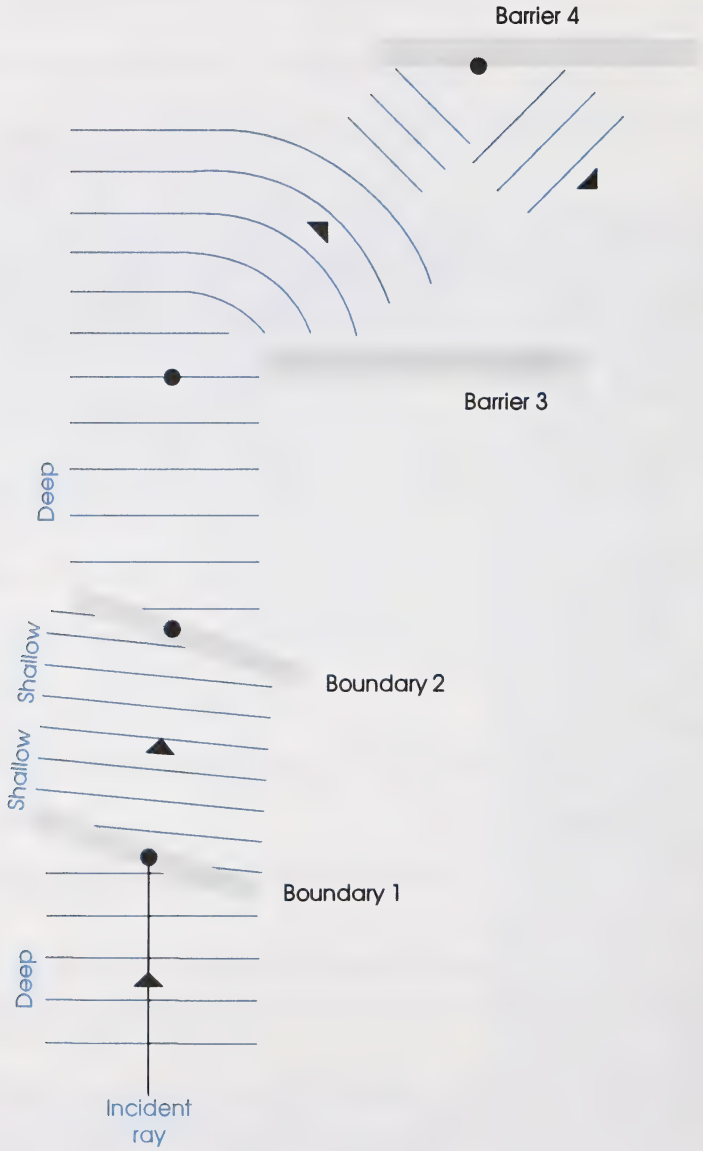
Extra Help

1. In this section you have learned about a number of different wave behaviours. Complete the missing parts of the following summary chart to help focus on the main ideas that explain each wave property.

Wave Property	Diagram to Illustrate This Wave Property	Point Form Explanation of Main Ideas	Note Any Changes in λ, f, v or A
Reflection from the Boundary of a More Dense Medium		The reflected wave is inverted.	The only variable to change is the amplitude, which is slightly smaller and inverted.
Reflection from the Boundary of a Less Dense Medium			
Reflection in Two Dimensions			
Refraction for a Wave Entering a Slower Medium			
Superposition of Identical Crests			
Superposition of an Equal-sized Crest and Trough			

2. The following diagram shows water waves encountering various barriers and boundaries in a ripple tank.

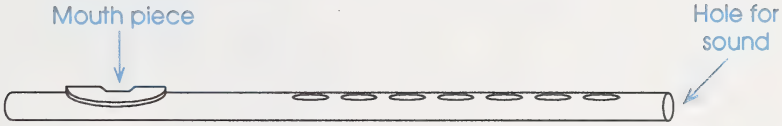
   a. Continue to draw the incident ray to show the changes in the direction of the wave fronts.



b. Complete the table by describing what happened at each boundary or barrier.

Boundary or Barrier	Property	Description	Changes in Variables
1			v f λ $\angle i < \angle r$
2			v f λ $\angle i > \angle r$
3			v f λ
4			v f λ

3. A flute can be treated as an open pipe that is designed to resonate with the note middle C (264 Hz) as its fundamental frequency when all the finger holes are closed. The following diagram shows the flute.



a. If the mouth piece and the hole for sound are the open ends, what distance should separate these two points? Assume that the flute and the air inside it are at 20°C and the speed of sound is 343 m/s.

b. Explain what the primary vibrator and the resonant vibrator are for a flute.

c. How would you expect the pitch of the flute to change if the finger hole nearest the mouth piece was left open?

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

Do **one** of the following questions.

1. Obtain the April 1992 copy of the magazine *Popular Science* and do a report on how the property of superposition is being applied in the cancellation of unwanted noise.

   Your report should include the following:

   - How the technology works in terms of the properties of waves
   - Where it works best and why
   - A list of present and future applications including the removal of sound berms
   - What safety considerations must be taken into account?

2. Building Your Own Wind Chimes

   - For this activity you will need to obtain these materials:

     – 2.1 m of 12.7-mm copper tubing
     – hacksaw or pipe cutter
     – drill with high speed bits
     – metal file
     – nylon fishing line
     – 30-cm^2 sheet of Plexiglas™ (or substitute $\frac{1}{4}$-inch plywood)

   - Cut the copper tubing into the following lengths:

     – 21.03 cm
     – 22.23 cm
     – 23.18 cm
     – 24.69 cm
     – 26.11 cm
     – 27.62 cm
     – 28.34 cm
     – 29.85 cm

   - Use the metal file to remove any rough edges caused by cutting the pipe.

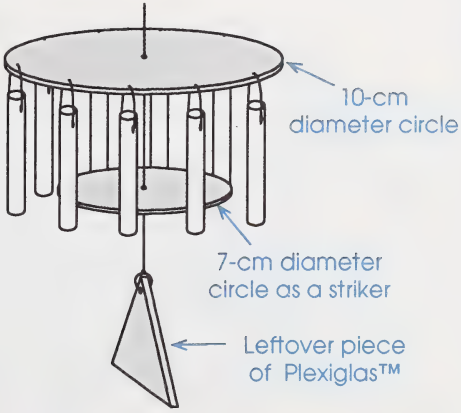
- Hold a tube upright in your hand and blow over the edge as shown. Repeat this step for all eight tubes.

a. Which tube produced the highest sound? Does this match what you learned earlier about resonant air columns?

- Use the drill to make a hole through each tube. Suspend each tube by passing a length of fishing line through the holes. Tap the suspended tube with another tube. Repeat this step for all eight tubes.

b. Was there a difference between the sound produced by tapping and the sound produced by blowing? If so, why does this difference exist?

- Cut out a 10-cm circle of Plexiglas™, drill eight holes around the circumference of the circle, and suspend the tubes from that circle. If you wish, a striker can be formed from the leftover Plexiglas™ as shown.



3. If you have access to the Critical Thinking package included with your textbook, do the exercise on page 20 relating to the property of superposition.

4. If you have access to laboratory facilities and the laboratory manual that accompanies the textbook, do the investigation which appears on page 81 of the laboratory manual. The investigation is called Experiment 14.1: Ripple Tank Waves.

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

You began this section by studying the behaviour of waves at boundaries. When a wave encounters a boundary, part of the wave is transmitted and part is reflected. The amount of the wave that is transmitted or reflected depends on the properties of each of the media along the boundary line.

When two-dimensional waves encounter a boundary, the transmitted wave may refract and change direction. If the boundary is more like a barrier and presents an opening or an edge to the wave, the wave can diffract by spreading out on the other side of the barrier.

The principle of superposition helps to explain the constructive and destructive interference of waves.

An understanding of the reflection, refraction, diffraction, and interference of waves provides great insight into a wide range of wave phenomena. Musical instruments in particular provide an especially interesting application of many of these ideas.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

MODULE SUMMARY

Without question, the activities in your life involve the characteristics and properties of waves. It would be a mistake to think that sound waves and water waves are the only ones that matter. Light waves could be considered the most important of all, since your sense of sight depends on your ability to receive and interpret light waves.

In the next module you will extend your investigation of waves to the study of light.

Appendix

Glossary

Activities

Extra Help

Enrichment

Glossary

amplitude – the maximum displacement of the medium from the equilibrium position

antinode – a point of maximum amplitude

boundary – the junction where one medium meets another

compression – a region where the particles of the medium are pushed closer together in a longitudinal wave

constructive interference – two waves combine to form a resultant amplitude that is larger than the amplitutde of either one of the initial waves

crest – a region of positive displacement on a transverse wave

destructive interference – two waves combine to produce a resultant amplitude that is smaller than the amplitude of either one of the initial waves

diffraction – the spreading of waves as they pass through an opening or by the edge of a boundary

Doppler effect – the change in frequency due to the relative motion between a wave source and a receiver

frequency – the number of complete vibrations or cycles in one second

fundamental frequency – the lowest frequency that makes up a sound

harmonics – overtones which are exact multiples of the fundamental frequency

incident wave – the initial or incoming wave

incident wave ray – a line that is perpendicular to incident wave fronts showing the velocity of the waves

longitudinal – running lengthwise

longitudinal wave – a wave in which the particles of the medium vibrate parallel to the velocity of the wave

loudness – a subjective sound characteristic that depends mainly on pressure changes at the ear

medium – the material that vibrates and carries the energy of the wave

node – a point of zero amplitude

normal – a line that is perpendicular to the boundary

one-dimensional – along a straight line

overtones – higher frequencies that are created in addition to the fundamental frequency

period – the time taken to make one complete vibration or cycle

pitch – a subjective sound characteristic that depends mainly on frequency

principle of superposition – The result of two waves overlapping can be found by adding the amplitudes of the two waves.

quality – the subjective characteristic of a sound that depends on the number and strength of the overtones created

rarefaction – a region where the particles of the medium are pulled further apart in a longitudinal wave

refraction – a change in the direction of a wave due to a change in speed between two media

reflected wave – the wave that reflects from a boundary

reflected wave ray – a line that is perpendicular to reflected wave fronts showing the velocity of the waves

shock wave – a constructive interference effect due to an object travelling faster than the speed of sound

sonic boom – the sound from an object travelling at supersonic speeds that is heard by observers

sound level – depends on the pressure for a given sound compared to the pressure of the most faintly heard sound

standing wave – a wave which appears to stand still due to the interference of two identical waves

supersonic – able to travel faster than the speed of sound

transverse – at right angles

transmitted wave – the part of the incident wave that enters the new medium

trough – a region of negative displacement on a transverse wave

two-dimensional – occurring on a flat surface

transverse wave – a wave in which the particles of the medium vibrate perpendicular to the velocity of the wave

universal wave equation – The speed of a wave equals the wavelength multiplied by the frequency.

wave – the transfer of energy through vibrations

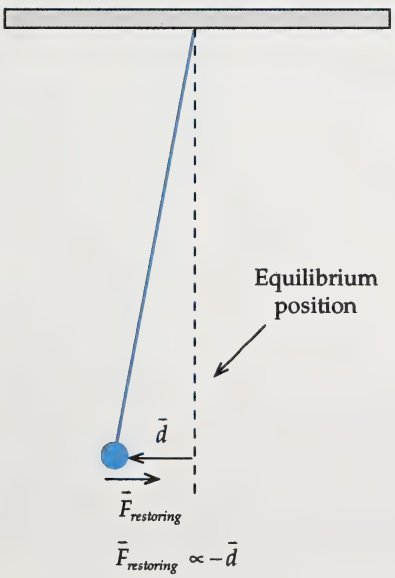
wave pulse – a single disturbance travelling through the medium

wavelength – the distance from a point on one wave to the corresponding point on the next wave

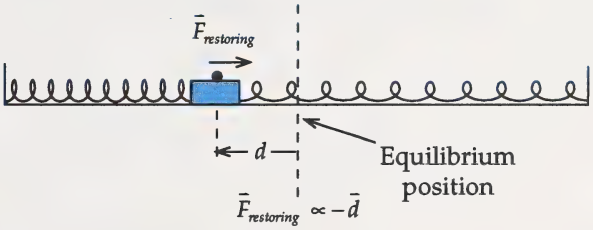
Suggested Answers

Section 1: Activity 1

1.

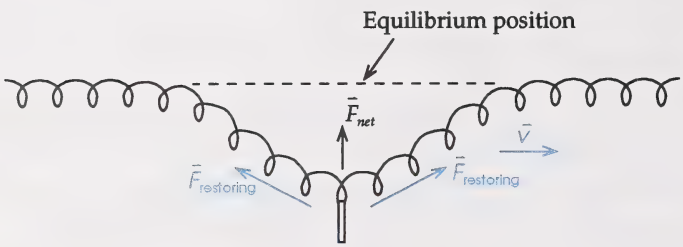


2.



3. The disturbance looks like a hump that moves through the spring.

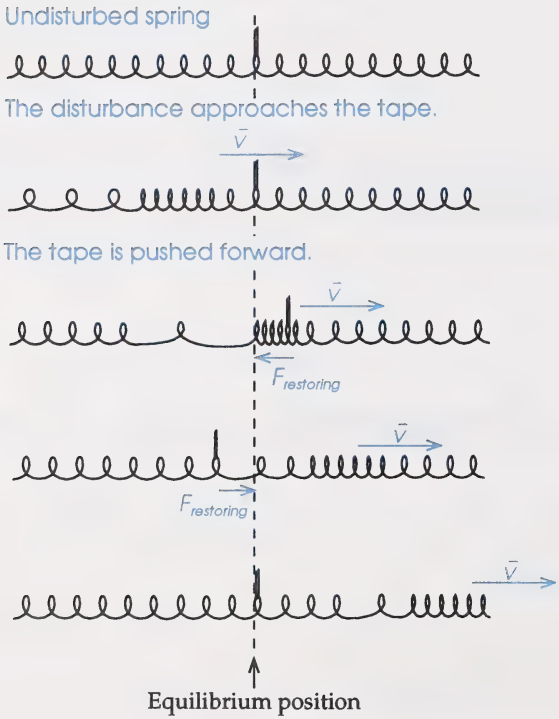
4.



5. The tape moves parallel to the restoring force, as shown in the answer to the previous question. The restoring force tends to pull the tape back towards the equilibrium position (in the opposite direction of the displacement).

6. The disturbance travels as a compressed group of springs from one end of the spring to the other. The tape moves towards the opposite end of the spring and then it recoils and moves towards the end that the disturbance came from.

7.



8. The tape moves parallel to the restoring force. The restoring force tends to pull the tape back to the equilibrium position (in the opposite direction of the displacement).

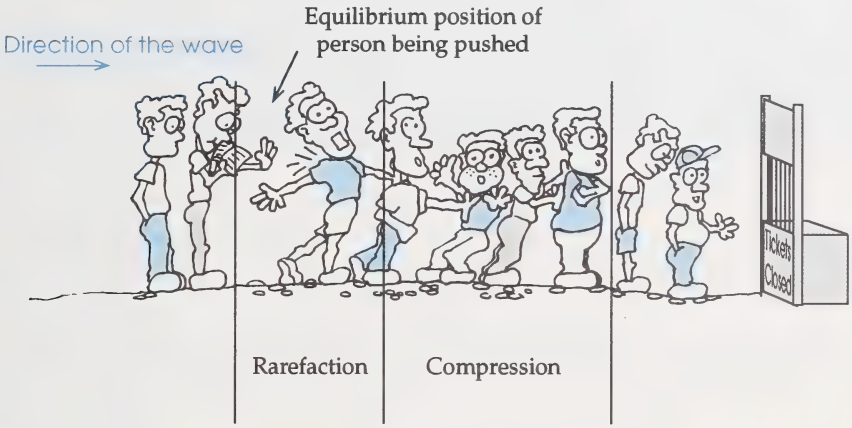
9. Without a restoring force or tension, the particles of the medium would have no reason to return to their initial equilibrium position. In other words, the particles would not vibrate and wave motion could not exist.

10. a. You could throw the water polo ball at your friend. The ball would do work on your friend's head and would transfer energy.

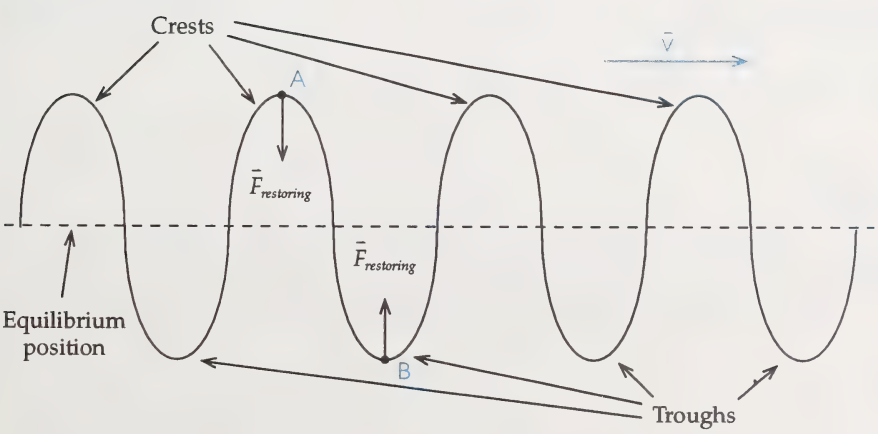
b. You could let a water wave carry energy to your friend. The water would only be temporarily disturbed from its position. You could also shout at your friend and let sound waves carry the energy.

11. a. This is a transverse wave.

b. This is a longitudinal wave.



12.



a. See the labels on the previous diagram.

b. point A: $A = 20$ mm
point B: $A = -20.5$ mm

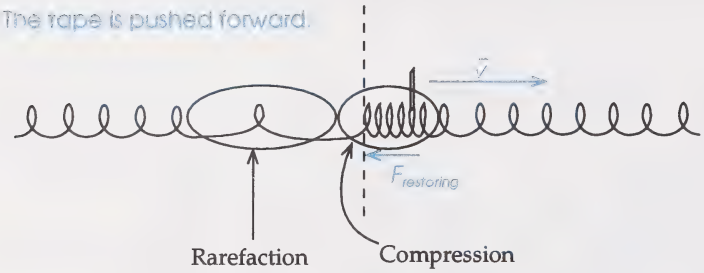
c. See the labels on the previous diagram.

d. This is a transverse wave because the particles of the medium vibrate perpendicularly to the velocity of the wave. This wave has crests and troughs (they are labelled on the previous diagram).

e. $T = \dfrac{30\text{ s}}{66\text{ cycles}} = 0.45\text{ s}$

$f = \dfrac{66\text{ cycles}}{30\text{ s}} = \dfrac{2.2\text{ cycles}}{1\text{ s}} = 2.2\text{ Hz}$ or $f = \dfrac{1}{T} = \dfrac{1}{0.45\text{ s}} = 2.2\text{ Hz}$

13. The rope is pushed forward.



a. position A: $A = +7.5$ mm
position B: $A = -8.5$ mm

b. This is a longitudinal wave since the particles of the medium move parallel to the velocity of the wave. This wave has compressions and rarefactions, as shown in the previous diagram.

c. $T = \dfrac{60\text{ s}}{96\text{ cycles}} = 0.625\text{ s} = 0.63\text{ s}$

$f = \dfrac{96\text{ cycles}}{60\text{ s}} = \dfrac{1.6\text{ cycles}}{1\text{ s}} = 1.6\text{ Hz}$ or $f = \dfrac{1}{T} = \dfrac{1}{0.625\text{ s}} = 1.6\text{ Hz}$

Section 1: Activity 2

1. Yes, measuring crest to crest gives the same value for wavelength as measuring trough to trough.

2. a. $\lambda = 40$ mm

b. $\lambda = 29.5$ mm

c. $\lambda = 9.7$ mm

d. $\lambda = 54$ mm

3. a. Exactly one wavelength is shown here. Therefore, $\lambda = 4.0\ \text{m}$.

b. One and a half wavelengths are shown in the 4.0-m space.

$$1\frac{1}{2}\lambda = 4.0\ \text{m}$$
$$\frac{3}{2}\lambda = 4.0\ \text{m}$$
$$\lambda = 2.\overline{6}\ \text{m}$$

c. Two wavelengths are shown in the 4.0-m space.

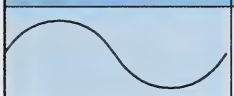
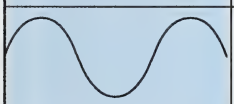
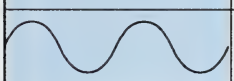
$$2\lambda = 4.0\ \text{m}$$
$$\lambda = 2.0\ \text{m}$$

d. One half of a wavelength is shown in the 4.0-m space.

$$\frac{1}{2}\lambda = 4.0\ \text{m}$$
$$\lambda = 8.0\ \text{m}$$

4.

Data for Standing Waves Made in a Spring

Wave Pattern	Wavelength (m)	Your Hand			The Wave		
		Vibrations in 30 s	Frequency (Hz)	Period (s)	Vibrations in 30 s	Frequency (Hz)	Period (s)
	4.0	53	1.8	0.57	52	1.7	0.58
	2.7	77	2.6	0.39	78	2.6	0.38
	2.0	108	3.6	0.28	109	3.6	0.28
	8.0	26	0.87	1.2	26	0.87	1.2

5. Question 5 is answered on the previous chart.

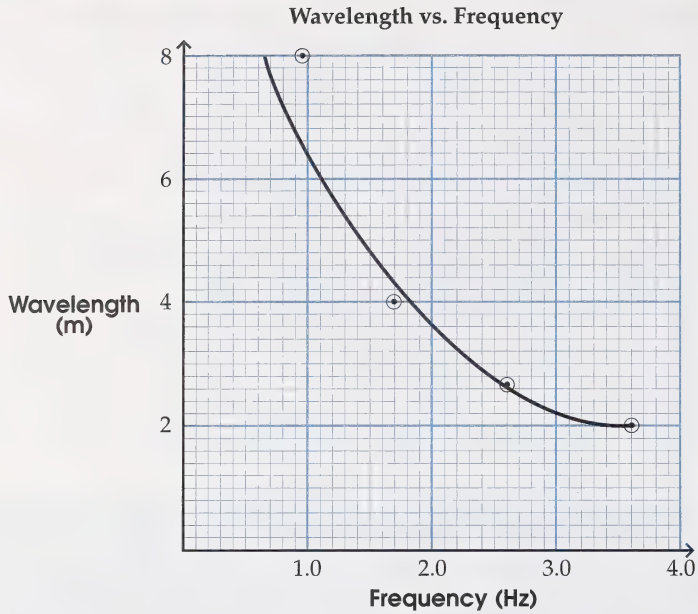
6. Question 6 is answered on the previous chart.

7. Question 7 is answered on the previous chart.

8. The periods and frequencies for the hand and the waves are identical (within experimental error).

9. Decreasing the wavelength requires an increase in frequency. Increasing the wavelength requires a decrease in frequency. In other words, wavelength and frequency are inversely related.

10.

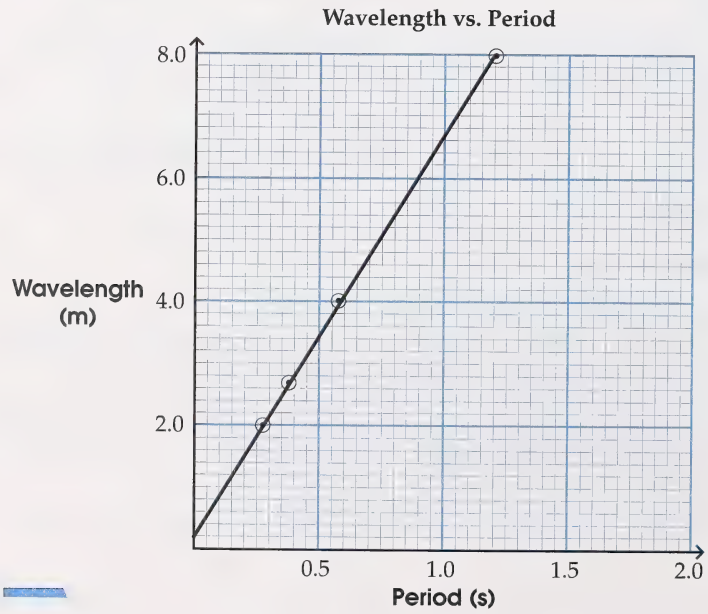


11. No, the graph should never touch the x-axis. This would imply that the value for wavelength was zero, which would in turn mean that there was no characteristic wave pattern.

12. No, the graph should never touch the y-axis. This would imply that the value for frequency was zero, which would in turn mean that there was no vibration occurring.

13. Wavelength increases as the period increases and decreases as the period decreases. The wavelength is directly related to the period.

14.



15. $\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{8.0\text{ m} - 0.2\text{ m}}{1.2\text{ s} - 0\text{ s}} = \frac{7.8\text{ m}}{1.2\text{ s}} = 6.5\text{ m/s}$

16. The units are metres per second, which suggests that the slope is a speed.

17. $d = 4(4.0\text{ m}) = 16\text{ m}$ $\qquad v = \frac{d}{t} = \frac{16\text{ m}}{2.4\text{ s}} = 6.7\text{ m/s}$

    $t = 2.4\text{ s}$

    $v = ?$

    The speed of a pulse is 6.7 m/s. The slope of the wavelength versus period graph was 6.5 m/s. These values are so close that it seems like the slope of the wavelength versus period graph is the speed of the wave.

18. Period and frequency are both determined by the source of the wave. In this case, the source is your hand.

19. Wavelength and frequency are inversely related. Increasing one requires that the other is decreased.

20. The slope of a wavelength versus period graph is the speed of the wave.

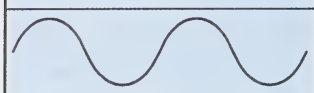
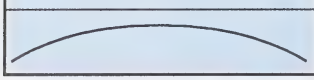
Section 1: Activity 3

1.

Data for a Pulse Travelling in a Spring			
Trial	**Distance (m)**	**Time (s)**	**Speed (m/s)**
1	16.0	1.80	8.9
2	8.0	0.90	8.9
3	4.0	0.45	8.9

2. No, the distance is not important. The only thing that matters for calculating the speed is that an accurate time can be matched to the distance.

3.

Applying the Universal Wave Equation to Waves on a Spring			
Wave Pattern	Wavelength (m)	Frequency (Hz)	Speed (m/s)
	4.0	1.7	6.8
	2.7	2.6	7.0
	2.0	3.6	7.2
	8.0	0.87	7.0

4. Referring to the first and third rows in the previous chart, it appears that doubling the frequency has little effect on the speed.

5. Referring to the first and fourth rows in the previous chart, it appears that doubling the wavelength has little effect on the speed.

6. Stainless steel seems to have its particles held in place with the largest restoring forces.

7. The molecules in air at 20°C are already moving faster than molecules in air at 0°C. Since the molecules are moving faster, they can pass vibrations at a greater speed.

8. a. $f = 262\text{ Hz}$
$v_{air} = 343\text{ m/s}$
$\lambda = ?$

$$v = \lambda f$$
$$\lambda = \frac{v}{f}$$
$$= \frac{343\text{ m/s}}{262\text{ Hz}}$$
$$= 1.31\text{ m}$$

b. $f = 262\text{ Hz}$
$v_{water} = 1440\text{ m/s}$
$\lambda = ?$

$$v = \lambda f$$
$$\lambda = \frac{v}{f}$$
$$= \frac{1440\text{ m/s}}{262\text{ Hz}}$$
$$= 5.50\text{ m}$$

c. $f = 262\text{ Hz}$
$v_{steel} = 5790\text{ m/s}$
$\lambda = ?$

$$v = \lambda f$$
$$\lambda = \frac{v}{f}$$
$$= \frac{5790\text{ m/s}}{262\text{ Hz}}$$
$$= 22.1\text{ m}$$

9. Textbook question 8. a.:

$f = 1.00 \times 10^6\ \text{Hz}$
$\lambda = 1.50\ \text{mm}$
$v = ?$

$$v = \lambda f$$
$$= \left(1.50 \times 10^{-3}\ \text{m}\right)\left(1.00 \times 10^6\ \text{Hz}\right)$$
$$= 1.50 \times 10^3\ \text{m/s}$$

Textbook question 8. b.:

$f = 1.00 \times 10^6\ \text{Hz}$
$T = ?$

$$T = \frac{1}{f}$$
$$= \frac{1}{1.00 \times 10^6\ \text{Hz}}$$
$$= 1.00 \times 10^{-6}\ \text{s}$$

Textbook question 8. c.:

The period in air is 1.00×10^{-6} s because the period, like frequency, depends on the source, not the medium.

Textbook question 9. a.:

$\lambda = 0.70\ \text{m}$
$v = 330\ \text{m/s}$
$\Delta t = 0.50\ \text{s}$
$f = ?$

$$v = \lambda f$$
$$f = \frac{v}{\lambda}$$
$$= \frac{330\ \text{m/s}}{0.70\ \text{m}}$$
$$= 471\ 1/\text{s}$$
$$= 4.7 \times 10^2\ \text{Hz}$$

Textbook question 9. b.:

$f = 471\ \text{Hz}$
$T = ?$

$$T = \frac{1}{f}$$
$$= \frac{1}{471\ \text{Hz}}$$
$$= 0.0021\ \text{s}$$

The time for one wave to be made is 0.0021 s. So, the number of waves emitted in 0.50 s is calculated as follows:

$$0.50\ \text{s} \div 0.0021\ \text{s} = 238\ \text{waves}$$
$$= 2.4 \times 10^2\ \text{waves}$$

Textbook question 9. c.:

$d = ?$
$t = 0.50\ \text{s}$
$v = 330\ \text{m/s}$

$$v = \frac{d}{t}$$
$$d = vt$$
$$= (330\ \text{m/s})(0.50\ \text{s})$$
$$= 165\ \text{m}$$
$$= 1.7 \times 10^2\ \text{m}$$

Textbook question 12:

string: $l = 5.30\ \text{m}$
$m = 15.0\ \text{g}$
$= 0.0150\ \text{kg}$
$T = ?$
$v = ?$

sound: $f = 125\ \text{Hz}$
$\lambda = 120\ \text{cm}$
$= 1.200\ \text{m}$

Step 1: Find the speed of the wave on the string.

$$v = \lambda f$$
$$= (1.200\ \text{m})(125\ \text{Hz})$$
$$= 150\ \text{m/s}$$

Step 2: Find the mass per unit length of the string.

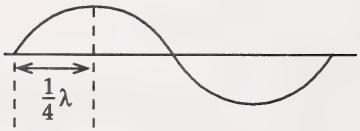
$$\mu = \frac{\text{mass}}{\text{length}} = \frac{0.0150\ \text{kg}}{5.30\ \text{m}} = 0.002\,83\ \text{kg/m}$$

Step 3: Find the force on the string.

$$v = \sqrt{\frac{T}{\mu}}$$
$$v^2 = \frac{T}{\mu}$$

$$T = v^2\mu$$
$$= (150\ \text{m/s})^2(0.002\,83\ \text{kg/m})$$
$$= 63.7\ \frac{\text{m}^{\cancel{2}}}{\text{s}^2}\frac{\text{kg}}{\cancel{\text{m}}}$$
$$= 63.7\ \text{N}$$

Textbook question 13. a.:



This is one-quarter of a wavelength.

Textbook question 13. b.:

If one-quarter of a wavelength takes 0.18 s, one full wavelength takes 0.72 s. The period of the wave is 0.72 s.

Textbook question 13. c.:

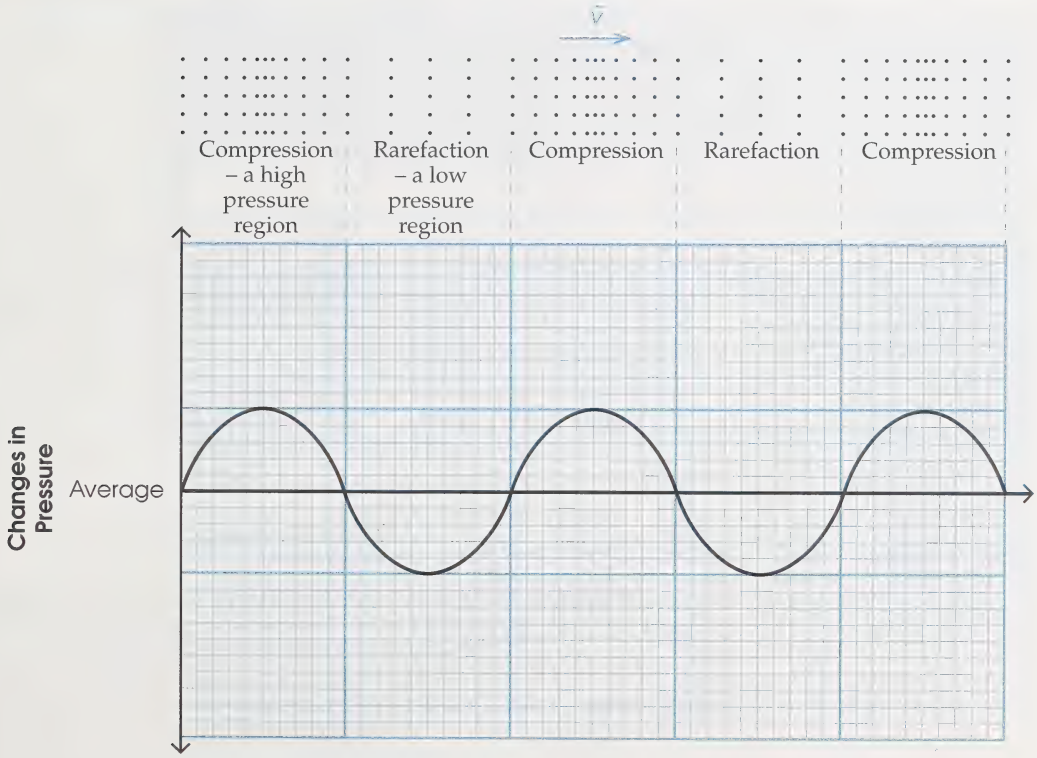
$T = 0.72\ \text{s}$
$f = ?$

$$f = \frac{1}{T} = \frac{1}{0.72\ \text{s}} = 1.4\ \text{Hz}$$

10.

Comparing Wave Types			
Wave Type	**Is the wave transverse or longitudinal?**	**What provides the restoring force for this wave?**	**What is an example of this wave?**
Tension Wave	transverse	tension	waves in a rope
Ripples	Surface waves are both transverse and longitudinal.	surface tension	ripples on the surface of the water
Gravity Wave	Surface waves are both transverse and longitudinal.	gravity	large ocean waves
Shear Wave	transverse	shear strength of a solid	*S* waves from an earthquake

11.



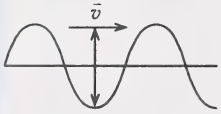
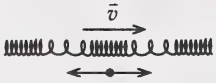
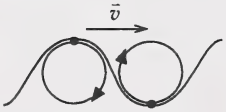
12.

Comparison Chart for Waves and Trains	
Wave Characteristic	**Train Characteristic**
Wavelength	the length of a car
Frequency	the number of cars that pass in a period of time
$v = \lambda f$	speed = (length of a car) (number of cars that pass in a time)

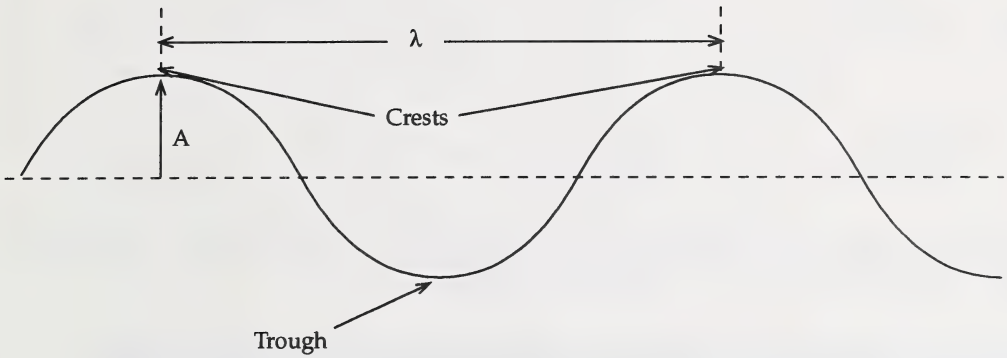
13. The velocity of a wave is determined by the restoring forces between the particles of the medium and by the inertia of the individual particles.

14. Mechanical waves require a material medium such as water, air, or steel for the wave to propagate. Electromagnetic waves require no medium and travel through space at the speed of light. Light, radio waves, and x-rays are electromagnetic waves. Matter waves describe the wave-like behaviour of electrons and other small particles, according to the principles of quantum mechanics.

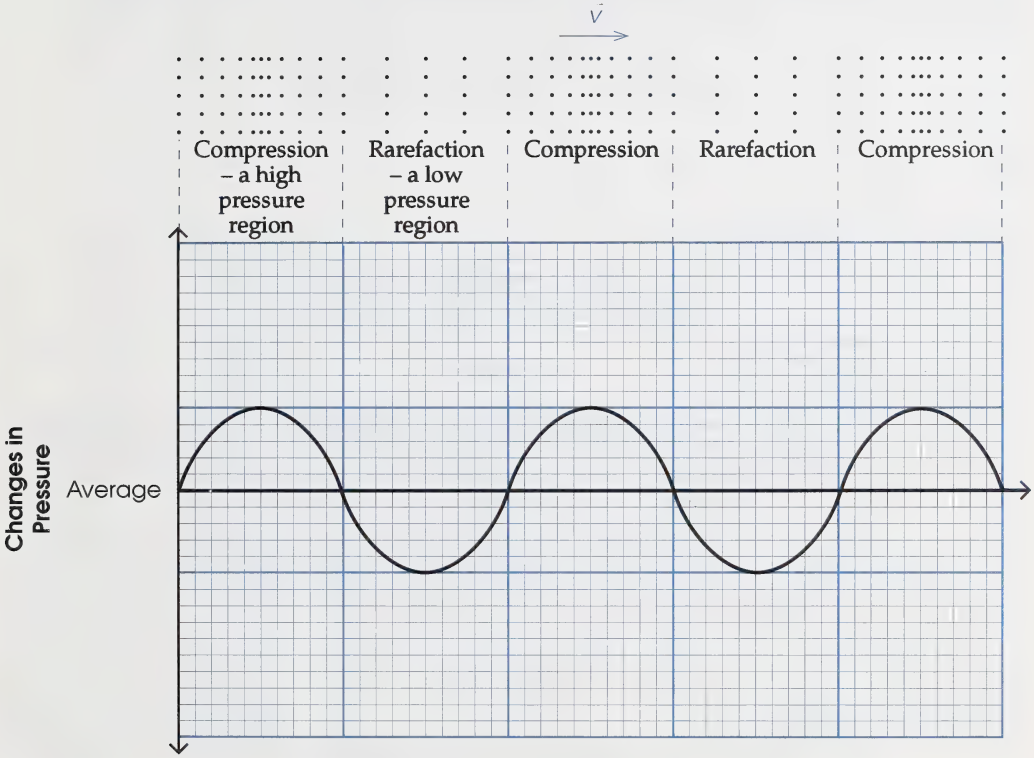
15.

A Comparison of Wave Types			
	Transverse Waves	**Longitudinal Waves**	**Surface Waves**
Definition	These waves cause the particles of the medium to vibrate perpendicularly to the velocity of the wave.	These waves cause the particles of the medium to vibrate parallel to the velocity of the wave.	These waves cause the particles to move both parallel and perpendicularly to the velocity of the wave.
Diagram of This Wave Type			
Example of This Wave Type	A wave on a rope or guitar string is an example of a transverse wave.	Sound is an example of a longitudinal wave.	Water waves are examples of surface waves.

16.



17.



18. The speed of waves in a rope is determined by the restoring forces between the particles of the rope and by the inertia of the individual particles. A rope that would allow waves to travel at a high speed would be under great tension, yet it would have a light mass for a given length. A guitar string would be an example of a fast medium for waves. A rope that would be a slow medium for waves would be under little tension and would have a great deal of mass per unit length. A huge mooring rope that is dangling loosely over the side of the ship would be a slow medium.

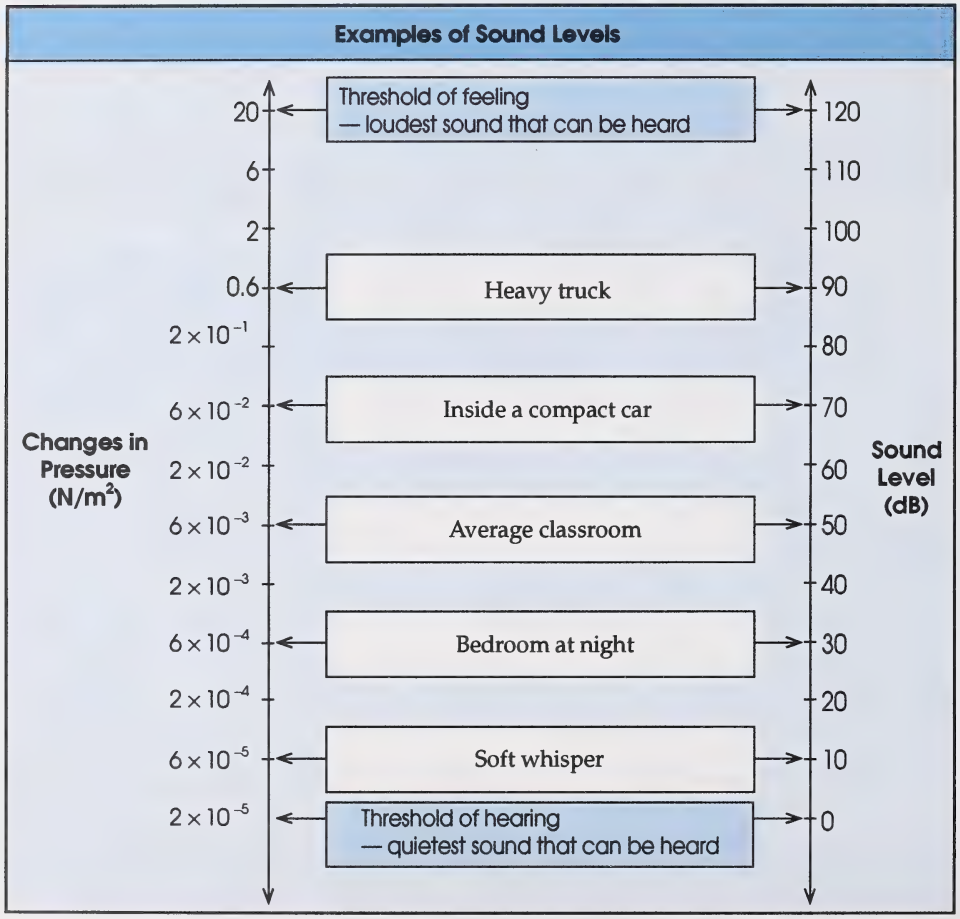
Section 1: Activity 4

1. $\lambda = 32$ mm $\quad A = 18$ mm

2. a. high-pitched
   b. low-pitched
   c. low-pitched
   d. high-pitched
   e. low-pitched
   f. high-pitched

3. Larger instruments contain a larger mass of air that has to vibrate to produce the sound. Due to inertia, it is more difficult to have a larger mass vibrate at high frequencies. Smaller instruments have less mass to vibrate, so it is easier for these instruments to vibrate at higher frequencies.

4.



5. a. $90\ \text{dB} - 10\ \text{dB} = 80\ \text{dB}$

   b. $\dfrac{0.6\ \text{N/m}^2}{6 \times 10^{-5}\ \text{N/m}^2} = 10\ 000$

   c. If one sound is 80 dB louder than another sound, the changes in pressure at the eardrum would be 10 000 times greater.

6. Human beings cannot hear sounds lower than 20 Hz, nor can they hear sounds higher than 20 000 Hz.

7. A sound level of 10 dB or less only allows people to hear frequencies between about 2000 Hz and 6000 Hz.

8. A sound level of 20 dB or less allows people to hear frequencies between about 200 Hz and 10 000 Hz.

9. a. According to the graph, you would not be able to hear any of the frequencies that were below about 100 Hz and above about 11 000 Hz.

   b. Music at low volume tends to sound rather flat with little bass and few high notes.

   c. This would boost the bass frequencies and the high frequencies so that the music would sound more realistic while being played at low volume.

10. When the tuning fork is struck on a piece of hardwood, the sound has a very sharp quality. It seems to be more harsh than when it is struck on an athletic shoe.

11. The results for this investigation will vary greatly, depending on the glasses chosen and your technique at getting them to sing. Sample results follow.

Subjective Characteristics of Singing Glasses			
Sketch Showing Relative Size and Shape of Each Glass			
Pitch	lowest	neither lowest nor highest	highest
Loudness	loudest	neither loudest nor quietest	quietest
Quality	• rich • full	• harsh • unpleasant	• pure • clear

12. This question is answered on the previous chart.

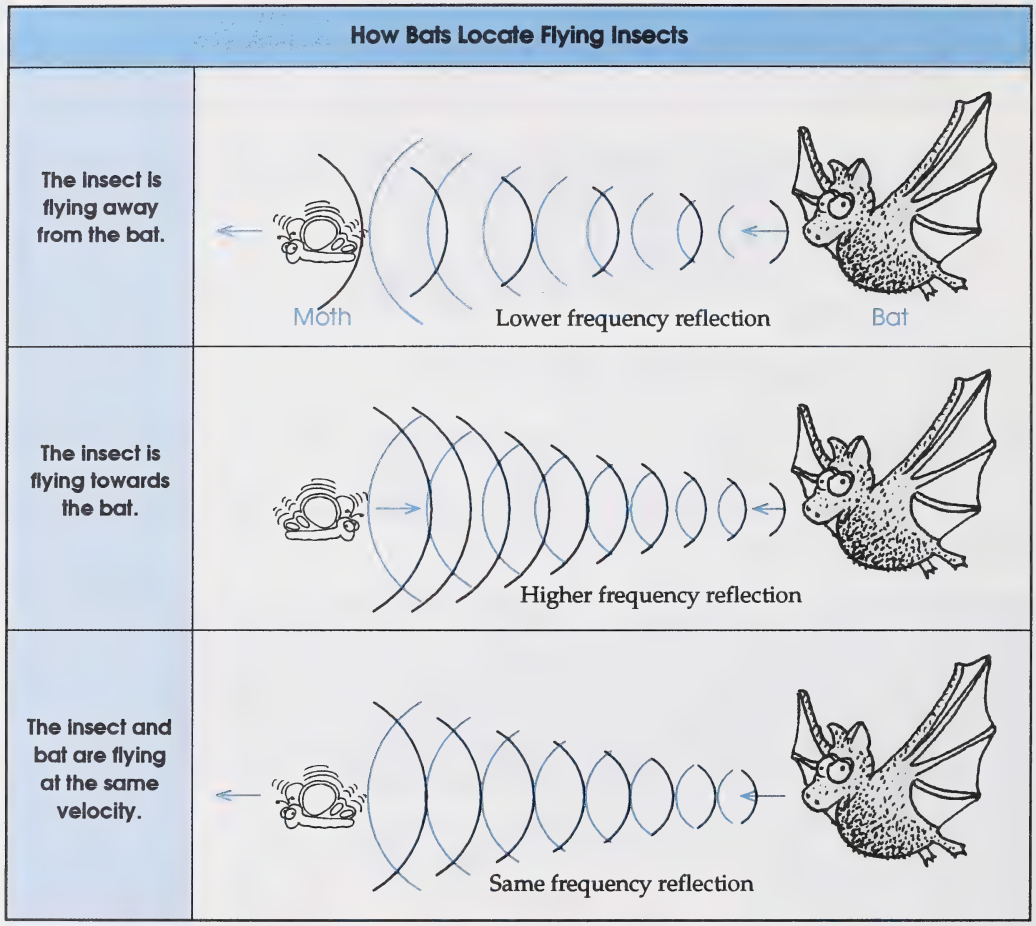
13. This question is answered on the previous chart.

14. The pitch changes the most when water is added to the glass.

15. Adding more water should cause the pitch to drop further.

16. Yes, the answers should be consistent. The water adds more mass to the glass, making it more difficult for the glass to vibrate at higher frequencies. As was mentioned in an earlier activity, a more massive object has a greater inertia and a greater resistance to change its motion. A singing glass, just like any other musical instrument, will naturally tend to vibrate at a lower frequency if the mass that must vibrate is greater.

17.



18. $f = 82\,000$ Hz
$v = 343$ m/s
$\lambda = ?$

$$v = \lambda f$$
$$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{82\,000 \text{ Hz}}$$
$$= 4.18 \times 10^{-3} \text{ m}$$

19. Bats use this technique to catch flying insects which have small body parts. Since only a small wavelength would reflect off such a tiny object, bats use sounds that have high frequencies and small wavelengths.

20. The sounds emitted by porpoises have higher frequencies, but these sounds travel in water, not air. Since the wavelength of a wave depends on both the medium and the frequency, it is possible for the underwater sounds of porpoises to have longer wavelengths than the airborne sounds of bats.

$v_{water} = 1500 \text{ m/s}$
$f = 2 \times 10^5 \text{ Hz}$
$\lambda = ?$

$$v = \lambda f$$
$$\lambda = \frac{v}{f}$$
$$= \frac{1500 \text{ m/s}}{2 \times 10^5 \text{ Hz}}$$
$$= 7.5 \times 10^{-3} \text{ m}$$

This is a larger wavelength than the sound of the bat in question 18.

Section 1: Follow-up Activities

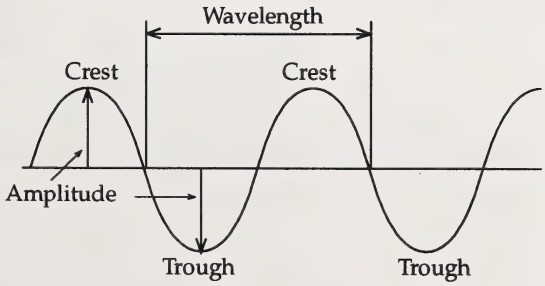
Extra Help

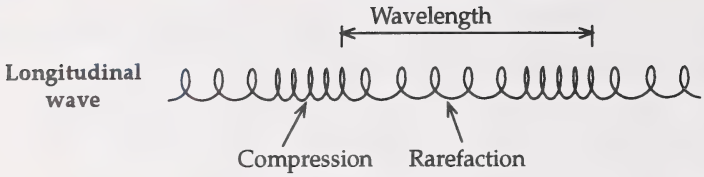
1.

Term	Symbol	Unit and Measure	Definition (Point Form)
Amplitude	A	cm or m	displacement from middle line to crest or trough
Wavelength	λ	cm or m	length of one wave pattern
Frequency	f	Hz, /s	the number of times a wave appears per second
Period	T	s	the time for one wave pattern
Speed	v	$\frac{\text{cm}}{\text{s}}$ or $\frac{\text{m}}{\text{s}}$	how fast a wave travels $v = \frac{d}{t}$ or $v = \lambda f$

2.

Transverse wave





3. a. $\lambda = 14$ squares $= 14$ cm

   b. amplitude $= 6$ squares $= 6.0$ cm

   c. $v = f\lambda = (4.0 \text{ cycles/s})(6.0 \text{ cm}) = 24 \text{ cm/s}$

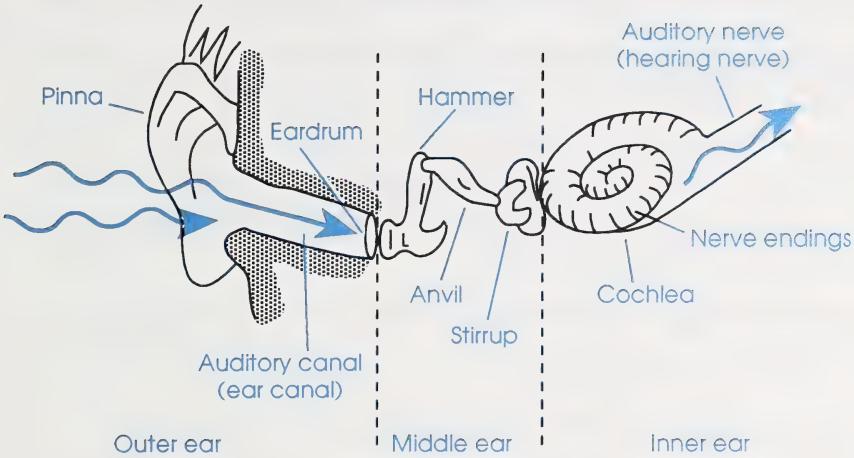
   d. $T = \frac{1}{f} = \frac{1}{4.0 \text{ cycles/s}} = 0.25 \text{ s}$

4.

Subjective Sound Characteristic	Factors that Determine This Characteristic	Two Examples that Illustrate This Characteristic
Pitch	Pitch depends mainly on the frequency of the sound.	• The tuba is a low-pitched instrument. • The buzzing of a mosquito is a high-pitched sound.
Loudness	Loudness depends mainly on the amplitude of the pressure variation.	• The sound that comes from the headphones of a portable stereo can be so loud that it does permanent damage to the ears. • A whisper is not very loud.
Quality	Quality depends on the number and strength of the overtones that are present.	• A note played on a piano usually has at least five overtones. This gives the piano a rich, full quality to its sound. • A tuning fork struck very gently on a piece of rubber has few overtones. Therefore, a very soft and warm sound is produced.

Enrichment

1. Your diagram of the ear should be similar to the one shown below.



The outer ear catches sound in the pinna. The sound then travels through the ear canal and pushes against the eardrum to make it vibrate. The vibrations cause the hammer, anvil, and stirrup to move. These bones pass the vibrations to the inner ear.

The inner ear consists of a spiral-shaped structure called the cochlea. The cochlea is filled with a liquid. The vibrations from the initial sound pass through this liquid and then stimulate tiny hair-like cells within the cochlea. It is the vibration of these hair-like cells that stimulates the auditory nerve that leads to the brain. In the brain, the signals from the auditory nerve are interpretted as sound.

2.

Types of Seismic Waves		
	P	**S**
Description	• primary wave • compresses and expands rock	• secondary or shear wave • make the earth's interior move at right angles to the direction of the wave
Wave Type	longitudinal	transverse
Relative Speed	fast	slow

a. S (or secondary) waves do not pass through the inner and outer cores.

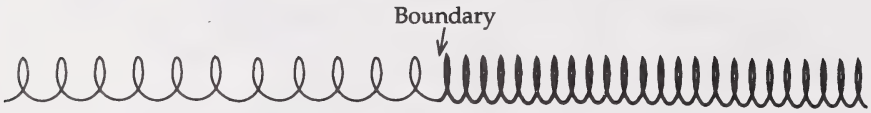
b. A seismograph is used to detect earthquakes. Its scale is the Richter Scale.

3. Suggested answers for this activity can be found in the teacher edition of the laboratory manual.

Section 2: Activity 1

1. A wave could not vanish because it is transferring energy. By the law of conservation of energy, energy cannot be destroyed, so the wave must continue until the energy is transferred into other forms.

2. The wave could either do work on a new medium or it could bounce off a boundary and return into the original medium.

3. 

4. The returning pulse is on the left side of the spring.

5. The returning pulse is on the right side of the spring.

6. The boundary is where the spring meets the chair.

7. The second medium is the chair. Very little of the original energy goes into this medium.

8. The amount of energy that is transferred to the chair is likely very small, especially if the chair is quite heavy. One way to detect the presence of wave energy in the chair would be to put your hand on the chair and feel for vibrations in the chair after the incident pulse strikes the chair.

9. The reflected wave is upside down or inverted.

10. $\bar{F}_{coils \rightarrow chair} = -\bar{F}_{chair \rightarrow coils}$

11. The reflected pulse is on the right side of the spring.

12. The returning pulse is on the left side of the spring.

13. The boundary is where the spring meets the twine.

14. The second medium for this investigation is the twine.

15. A small portion of the initial energy was transferred into the twine. The twine was observed to vibrate back and forth.

16. When waves reflect from the boundary of a less dense medium, they reflect upright on the same side as the initial wave.

17. A transmitted wave is the part of the incident wave that enters the new medium.

18. If the two media are very similar in density, most of the wave energy will be transmitted.

19. If part of the energy is reflected back into medium 1 as an inverted wave, medium 2 must be slightly more dense than medium 1.

20. Part a of Figure 14-9 shows an upright wave travelling to the right. This is the incident wave. The reflected wave shown in part b of that figure is also upright. This means that the second medium is less dense, while the first medium is the one with the greater density.

21. a.

b. The spring on the left has less massive coils, so they have less inertia and can react faster to vibrations within the spring. Therefore, the spring on the left would pass waves at a greater speed.

c. The frequency in each spring would be the same because frequency depends on the source, not the medium.

d. The factors that influence the wavelength of a wave on a spring can be determined by using the universal wave equation.

$$v = \lambda f$$

$$\lambda = \frac{v}{f}$$

The spring on the left will have waves with greater wavelength since this spring passes the waves at a greater speed.

22. The answers to these problems can be found on page 676 of your textbook.

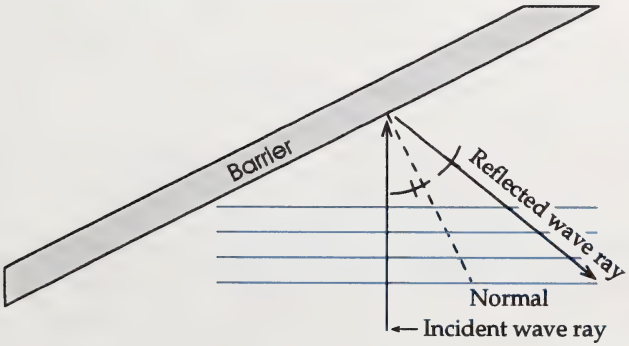
Section 2: Activity 2

1. The incident wave ray is a line that is perpendicular to the incident wave fronts. This ray shows the direction of the incident waves.

The reflected wave ray is a line that is perpendicular to the reflected wave fronts. This ray shows the direction of the reflected waves.

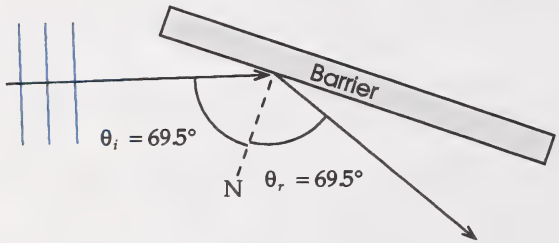
The normal is a line that is perpendicular to the boundary. The normal is drawn at the point where the incident wave ray strikes the boundary.

2.

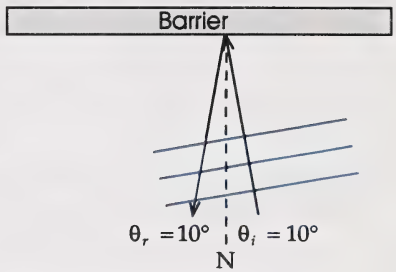


3. If the drawing is done carefully, the angle of incidence equals the angle of reflection. As shown on the previous diagram, these angles are measured from the normal.

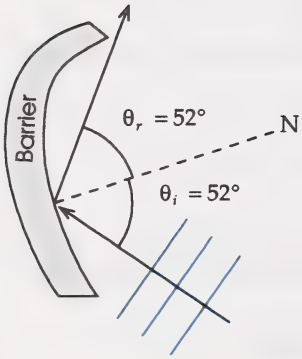
4. a.



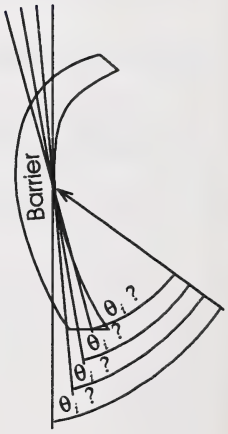
b.



c.



5. A normal can be drawn to any surface, even a curve, as shown in the answer to question 4. c. This means that angles of incidence and reflection can be measured from any surface. However, if angles were measured from the ray to the barrier, it would be unclear where to measure the angle. This is shown in the following diagram.



6. The frequency of the transmitted wave would also be 3.6 Hz because the frequency does not depend on the medium.

7. Incident wave:

$f = 3.6$ Hz
$v = 4.8$ m/s
$\lambda = ?$

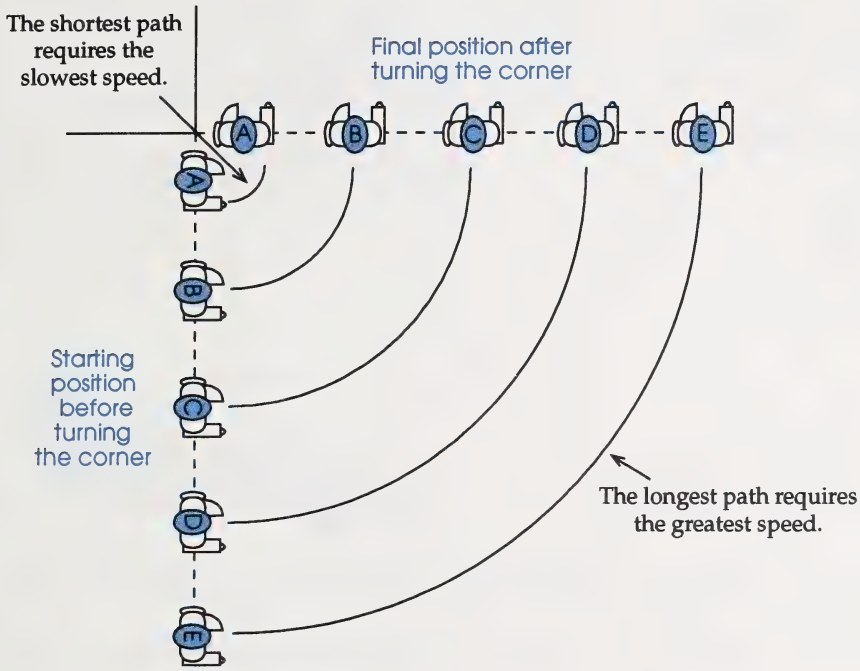
$$v = \lambda f$$
$$\lambda = \frac{v}{f}$$
$$= \frac{4.8 \text{ m/s}}{3.6 \text{ Hz}}$$
$$= 1.3 \text{ m}$$

Transmitted wave:

$f = 3.6$ Hz
$v = 2.4$ m/s
$\lambda = ?$

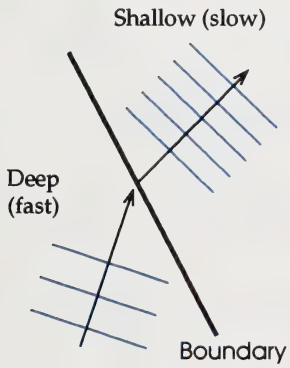
$$v = \lambda f$$
$$\lambda = \frac{v}{f}$$
$$= \frac{2.4 \text{ m/s}}{3.6 \text{ Hz}}$$
$$= 0.67 \text{ m}$$

8.

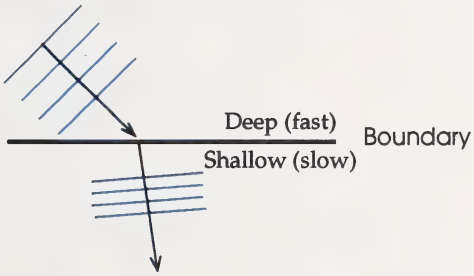


All members of the marching band have to arrive at the final position at the same time, although the marcher labelled A travels a short distance and the marcher labelled E travels a longer distance. The only way this can happen is for the marchers to have different speeds. The further the marchers are from the inside of the turn, the faster they have to go.

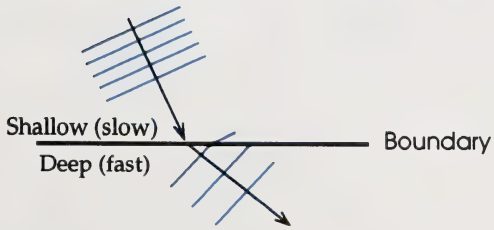
9. a.



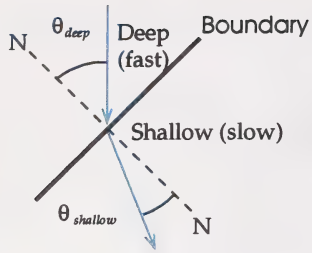
b.

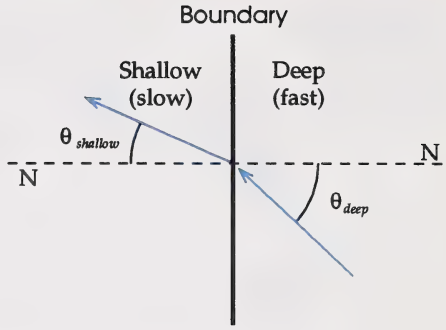


c.

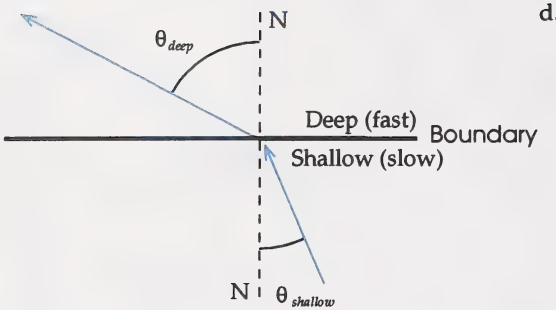


10. a.

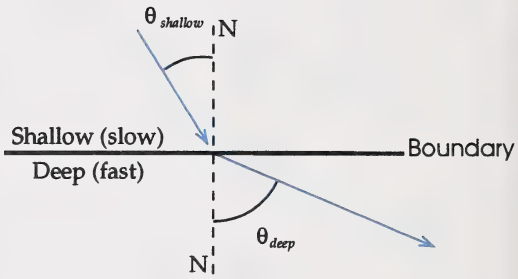




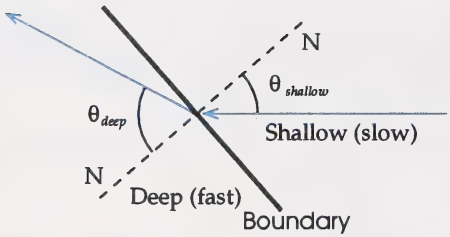
c.



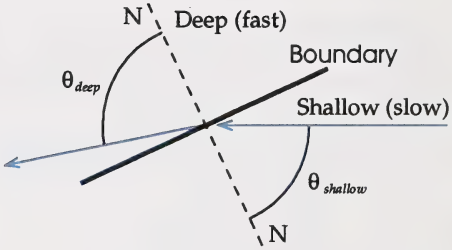
d.



e.



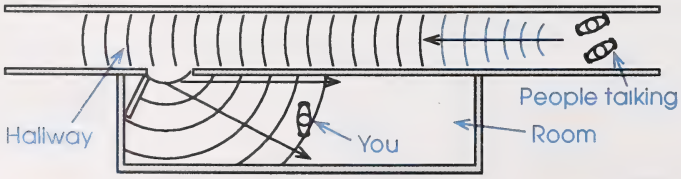
f.



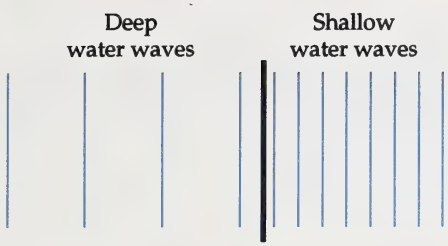
11. The answer to this question is found on the previous diagrams.

12. The medium which passes waves with the greatest speed is also the medium with the greatest angle between the wave ray and the normal. In all cases, the angle on the deep water side was larger than the angle on the shallow water side.

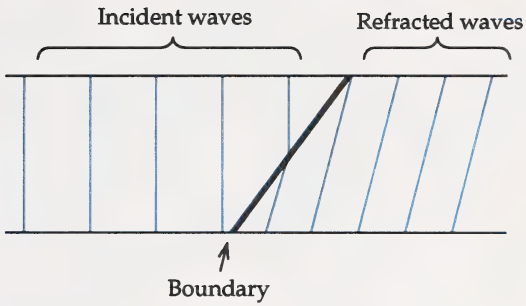
13. Diffraction will be greatest when the wavelength is larger than the opening that it is passing through.



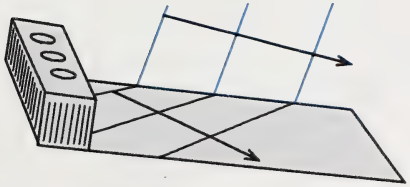
15.



16.



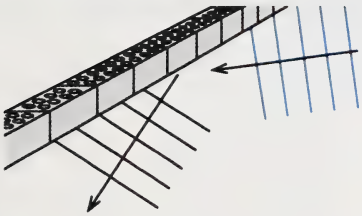
17.



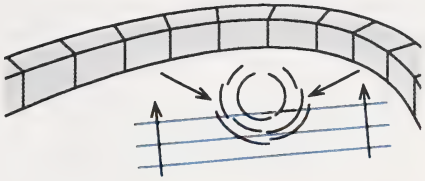
18. The region identified by the X is a region of shallow water. The shallow water has the effect of slowing the waves down, causing them to bunch together and bend towards the shallow area.

19. No, the reflected waves and the incident waves pass through each other.

20.



21.

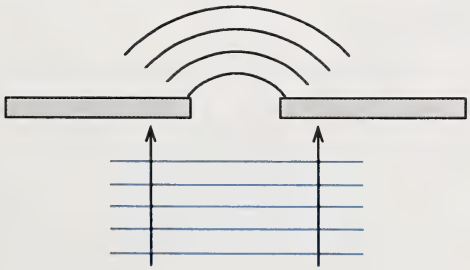


22. When a crest meets a crest, the result is a very large crest. This is also called an antinode.

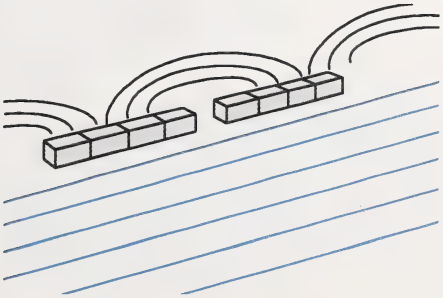
23. When a crest meets a trough, the result is a region of zero amplitude. This is called a node or a point of annulment.

24. The sideways portions of the circular waves annul or cancel one another out.

25.



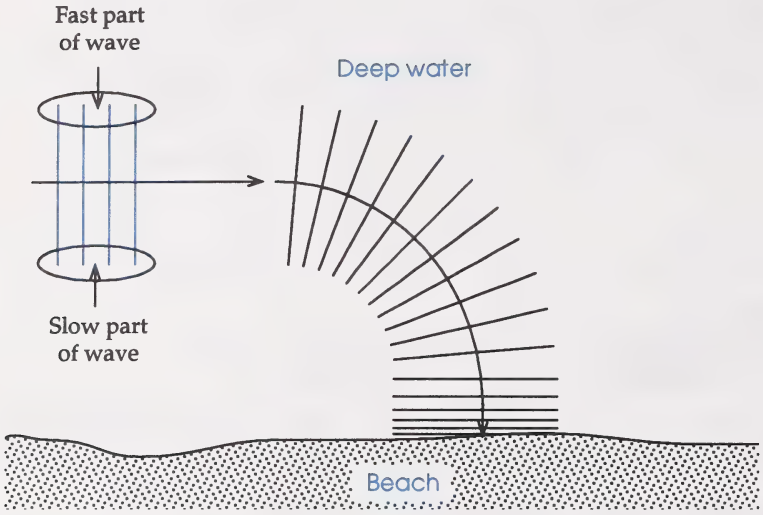
26.



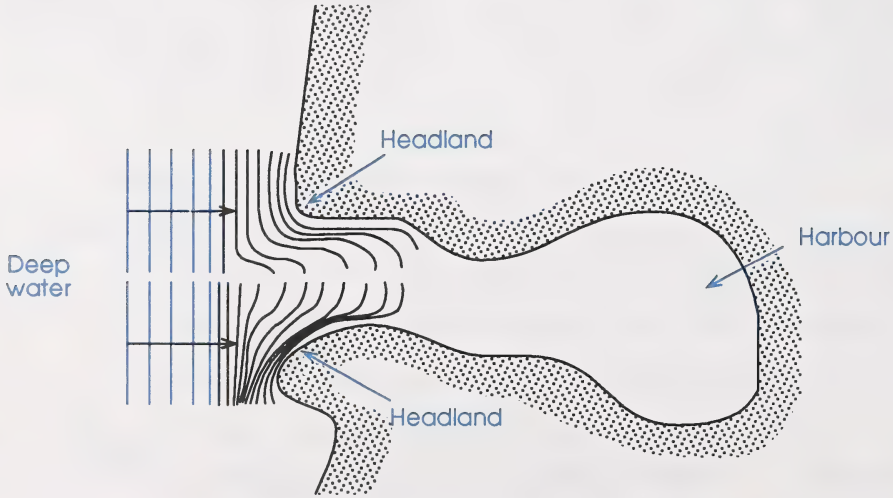
27. A standing wave is given that name because it appears to be standing still.

28. a. Waves travel slower in shallow water than in deep water. This means that part of the wavefront is travelling slowly and part of the wavefront is travelling fast. This has the effect of turning the wave.

b.

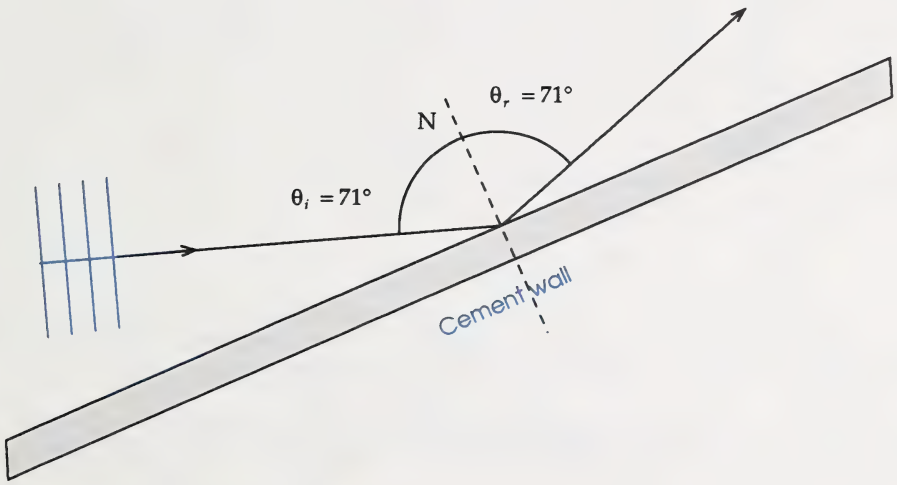


29. a. As shown in the following diagram, the deep water waves are turned toward the headlands. Only a small part of the deep waves are allowed to continue into the harbour.

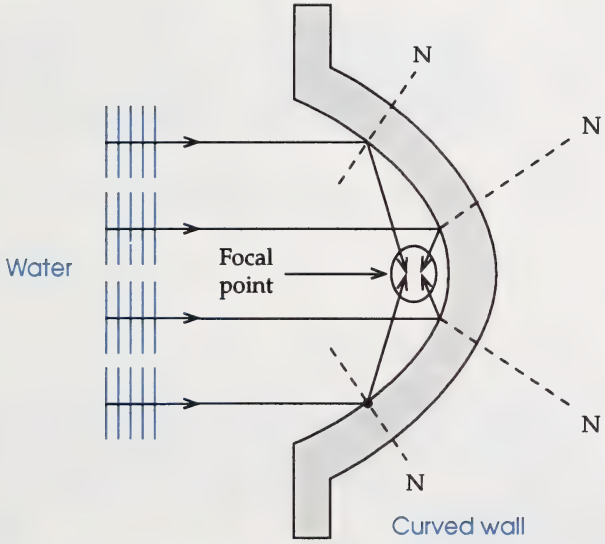


b. The headlands are pounded the hardest because they take the energy of the part of the waves that travel straight for them and the energy of the waves that are refracted toward them at the mouth of the harbour.

30.



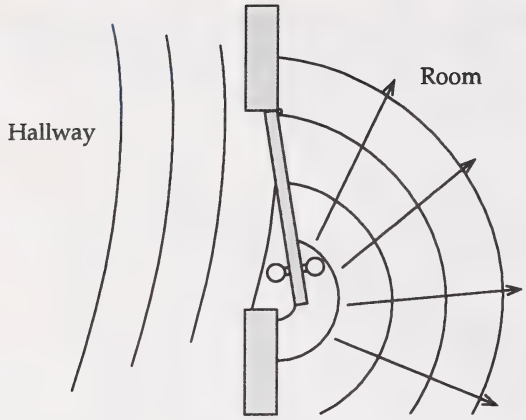
31. a.



b. The answer to this question is on the previous diagram.

c. The satellite dish would reflect all the microwaves to the focal point. This is the place that the sensitive detector for the microwaves would be put.

32.



The opening is small compared to the wavelength of most sound waves so the sound waves diffract as they pass from the hallway into the room.

33. a. The long wavelength sounds leave the speakers of the stereo and pass through the door, diffracting into the hallway and into the next room. This occurs because the wavelength of most low pitched bass notes is larger than a doorway.

$f = 100\text{ Hz}$

$v = 343\text{ m/s}$

$\lambda = ?$

$$v = \lambda f$$

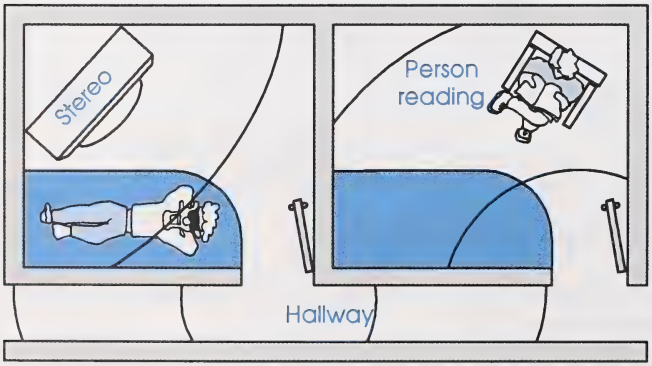
$$\lambda = \frac{v}{f}$$

$$= \frac{343\text{ m/s}}{100\text{ Hz}}$$

$$= 3.43\text{ m}$$

Most doorways are only 0.8 m wide.

b.



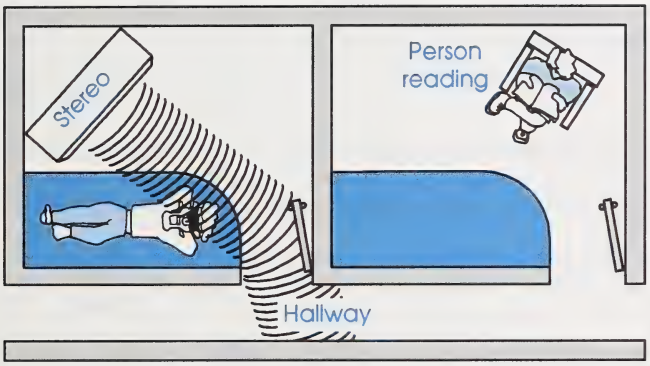
c. The small wavelength sounds leave the stereo speakers, but diffract very little as they pass out into the hallway. This occurs because the wavelength of most high frequency notes is much smaller than a doorway.

$f = 10\,000$ Hz
$v = 343$ m/s
$\lambda = ?$

$$v = \lambda f$$
$$\lambda = \frac{v}{f}$$
$$= \frac{343 \text{ m/s}}{10\,000 \text{ Hz}}$$
$$= 0.0343 \text{ m}$$
$$= 3.43 \text{ cm}$$

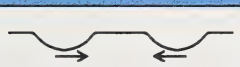
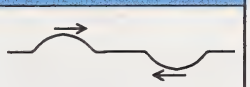
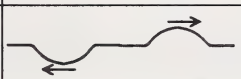
This is much smaller than a 0.8-m doorway.

d.



Section 2: Activity 3

1. Your data chart should look similar to the example given.

Observations for Overlapping Waves			
	Crest Meets Crest	Trough Meets Trough	Crest Meets Trough
Before			
During			
After			

2. Question 2 is answered on the previous data chart.

3. Question 3 is answered on the previous data chart.

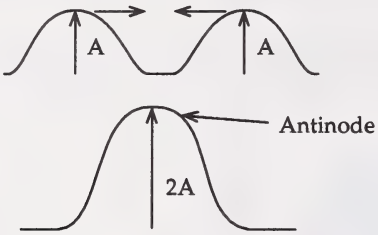
4. The observations for a crest meeting a trough provide the best insights into the answer to this question. Referring to the sample answers provided earlier, the trough continues travelling to the left while the crest continues moving to the right. This suggests that the pulses pass through each other.

5. The results of two waves overlapping can be found by adding the amplitudes of the two waves. This is known as the principle of superposition.

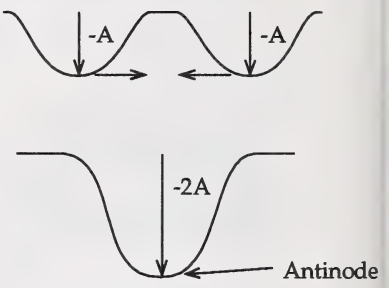
6. The principle of superposition states that the resulting amplitude from two overlapping waves can be found by adding the amplitudes of the two waves.

7. Constructive interference occurs when two waves combine to produce a resultant amplitude that is larger than the amplitude of either one of the initial waves. The following diagrams illustrate this idea.

Crest meets crest



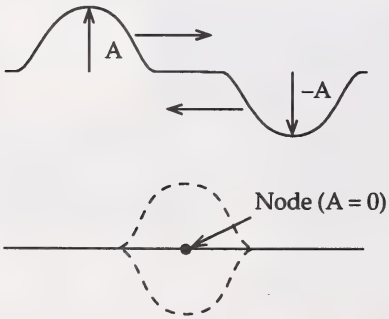
Trough meets trough



8. Destructive interference occurs when two waves combine to produce a resultant amplitude that is smaller than the amplitude of either one of the initial waves.

   The following diagram illustrates this idea.

   Crest meets trough



9. Mechanical resonance occurs when small forces are applied at specific intervals of time to increase an object's amplitude of vibration.

10. Your hand provided the small external force.

11. To create a standing wave in a spring, the time interval of the hand had to exactly match the time for a pulse to travel to the other end of the spring and back. The time for the pulse to travel down in back was determined by the length of the spring and the speed of the pulse on the spring.

12. node – A compression meets a rarefaction, causing a cancellation of the sound wave. A node is a quiet region because there is very little change in air pressure.

    antinode – A compression meets a compression, creating a larger compression, or a rarefaction meets a rarefaction, creating a larger rarefaction. A node would be heard as a louder region because there are large changes in air pressure.

13. The sound was alternately louder and quieter as the tuning fork was turned.

14. A node is formed when a compression meets a rarefaction. An antinode is formed when a compression meets a compression and when a rarefaction meets a rarefaction.

15. A node is created when a crest meets a trough. When looking at the pattern made when light passes through a ripple tank, crests produce a bright region and troughs produce a dark region. A node is neither a crest nor a trough, so it tends to look grey.

16. An antinode is created when a crest meets a crest, which creates a very high crest that tends to look like a bright region when light passes through it. An antinode can also be created when a trough meets a trough, which creates a very deep trough that tends to look like a dark region.

17. The pitch of the sound has changed due to the Doppler effect. Since the source is moving toward Observer B, the result is an increase in pitch. Since the source is moving away from Observer A, the result is a drop in pitch.

18. A bullet is much smaller than a jet aircraft, so it would disturb less air.

19. No, a sonic boom is produced the whole time that the aircraft is flying faster than the speed of sound.

Section 2: Activity 4

1. For a sound to be musical, it must be pleasing to the listener's ear. This is a subjective judgement which can vary from person to person.

2. The textbook uses the idea of pressure variations to represent the standing waves within pipes.

3. A pipe which is open at both ends has particles at both ends that are free to move in and out of the pipe. Since there is nothing to hold these particles in place, the pressure remains the same as the atmospheric pressure. These particles do not have any variation from atmospheric pressure and so they are pressure nodes.

4. a. $l = 0.686\text{ m}$
$v = 343\text{ m/s}$
$\lambda_1 = ?$
$f_1 = ?$

$\frac{1}{2}\lambda_1 = l$ for open pipes

$v = \lambda_1 f_1$

$f_1 = \frac{v}{\lambda_1}$

$= \frac{343\text{ m/s}}{1.372\text{ m}}$

$= 250\text{ Hz}$

$\lambda_1 = 2l$

$= 2(0.686\text{ m})$

$= 1.372\text{ m}$

The fundamental frequency of this pipe is 250 Hz. The first three overtones would be as follows:

$f_2 = 2f_1$
$= 2(250\text{ Hz})$
$= 500\text{ Hz}$

$f_3 = 3f_1$
$= 3(250\text{ Hz})$
$= 750\text{ Hz}$

$f_4 = 4f_1$
$= 4(250\text{ Hz})$
$= 1000\text{ Hz}$

b. $l = 1.715\text{ m}$
$v = 343\text{ m/s}$
$\lambda_1 = ?$
$f_1 = ?$

$\frac{1}{2}\lambda_1 = l$ for open pipes

$v = \lambda_1 f_1$

$f_1 = \frac{v}{\lambda_1}$

$= \frac{343\text{ m/s}}{3.43\text{ m}}$

$= 100\text{ Hz}$

$\lambda_1 = 2l$

$= 2(1.715\text{ m})$

$= 3.43\text{ m}$

The fundamental frequency is 100 Hz. The first three overtones are as follows:

$f_2 = 2f_1$
$= 2(100\text{ Hz})$
$= 200\text{ Hz}$

$f_3 = 3f_1$
$= 3(100\text{ Hz})$
$= 300\text{ Hz}$

$f_4 = 4f_1$
$= 4(100\text{ Hz})$
$= 400\text{ Hz}$

5. $f_1 = 20\text{ Hz}$
$v = 343\text{ m/s}$
$\lambda = ?$
$l = ?$

$v = \lambda f_1$

$\lambda = \frac{v}{f_1}$

$= \frac{343\text{ m/s}}{20\text{ Hz}}$

$= 17.15\text{ m}$

$\frac{1}{2}\lambda_1 = l$ for open pipes

$l = \frac{1}{2}(17.15\text{ m})$

$= 8.575\text{ m}$

$= 8.6\text{ m}$

6. $f_2 = 20\,000\text{ Hz}$
$v = 343\text{ m/s}$
$\lambda_1 = ?$
$l = ?$

$f_2 = 2f_1$
$f_1 = \frac{f_2}{2}$
$= \frac{20\,000\text{ Hz}}{2}$
$= 10\,000\text{ Hz}$

$v = \lambda_1 f_1$
$\lambda_1 = \frac{v}{f_1}$
$= \frac{343\text{ m/s}}{10\,000\text{ Hz}}$
$= 0.0343\text{ m}$

$\frac{1}{2}\lambda_1 = l$ for open pipes
$l = \frac{1}{2}(0.0343\text{ m})$
$= 0.0172\text{ m}$

7. a. $l = 0.343\text{ m}$
$v = 343\text{ m/s}$
$\lambda_1 = ?$
$f_1 = ?$

$\frac{1}{4}\lambda_1 = l$ for closed pipes
$\lambda_1 = 4l$
$= 4(0.343\text{ m})$
$= 1.372\text{ m}$

$v = \lambda_1 f_1$
$f_1 = \frac{v}{\lambda_1}$
$= \frac{343\text{ m/s}}{1.372\text{ m}}$
$= 250\text{ Hz}$

The fundamental frequency for this pipe is 250 Hz. The first three overtones for this pipe are the first three odd-numbered multiples of the fundamental frequency.

$f_3 = 3f_1$
$= 3(250\text{ Hz})$
$= 750\text{ Hz}$

$f_5 = 5f_1$
$= 5(250\text{ Hz})$
$= 1250\text{ Hz}$

$f_7 = 7f_1$
$= 7(250\text{ Hz})$
$= 1750\text{ Hz}$

b. $l = 1.75\text{ m}$
$v = 343\text{ m/s}$
$\lambda_1 = ?$
$f_1 = ?$

$\frac{1}{4}\lambda_1 = l$ for closed pipes

$v = \lambda_1 f_1$
$f_1 = \frac{v}{\lambda_1}$
$= \frac{343\text{ m/s}}{7.00\text{ m}}$
$= 49.0\text{ Hz}$

The fundamental frequency for this pipe is 49.0 Hz. The first three overtones for this pipe are the first three odd-numbered multiples of the fundamental frequency.

$f_3 = 3f_1$
$= 3(49.0\text{ Hz})$
$= 147\text{ Hz}$

$f_5 = 5f_1$
$= 5(49.0\text{ Hz})$
$= 245\text{ Hz}$

$f_7 = 7f_1$
$= 7(49.0\text{ Hz})$
$= 343\text{ Hz}$

8. $l = 3.0\text{ cm}$
$= 3.0 \times 10^{-2}\text{ m}$
$v = 343\text{ m/s}$
$\lambda_1 = ?$
$f_1 = ?$

$\frac{1}{4}\lambda_1 = l$ for closed pipes
$\lambda_1 = 4l$
$= 4(3.0 \times 10^{-2}\text{ m})$
$= 0.12\text{ m}$

$v = \lambda_1 f_1$
$f_1 = \frac{v}{\lambda_1}$
$= \frac{343\text{ m/s}}{0.12\text{ m}}$
$= 2858\text{ Hz}$
$= 2.9 \times 10^3\text{ Hz}$

9. The reason that people are most sensitive to sounds just under 3000 Hz is that these sounds are increased in amplitude because they match the resonant frequency of the auditory canal.

10. The answers to these problems are found on pages 676 and 677 of your textbook.

11. There are many possible approaches to this investigation. One possibility is presented here.

Setup:

- Put masking tape down the side of the air column tube so that you will be able to mark it later on.
- Fill up your container with water.
- To finish your setup, refer to Figure 15-8 on page 315 of your text. You will substitute the bottom of your runner as your hammer. Use the plastic tube as the air column and the bucket of water instead of the cylinder of water.

Procedure:

- Put the air column in the water as far as it will go.
- Strike the tuning fork on your runner and position it directly above the air column.
- Move the air column slowly up out of the water and listen for the first loud spot.
- Mark this level on the tape on the air tube.
- Listen for the second loud spot as you continue to raise the tube out of the water.
- Mark this point on the air column.
- Repeat this procedure at least three times and average your results.

Hints:

- Try to keep the tuning fork in the same place just above the air column as you move it out of the water.
- You may restrike the tuning fork between loud points if it is becoming too faint to hear.

Observations:

$f = 1024$ Hz (tuning fork)
$d = 0.17$ m (between loud spots)

Analysis:

The loud spots correspond to the fundamental frequency and the third harmonic. These frequencies occur when the length of the closed pipe is exactly $\frac{1}{4}\lambda$ and $\frac{3}{4}\lambda$. This means that the loud spots are separated by $\frac{1}{2}\lambda$.

$$\frac{1}{2}\lambda = 0.17 \text{ m}$$
$$\lambda = 0.34 \text{ m}$$

$$\begin{aligned} v &= \lambda f \\ &= (0.34 \text{ m})(1024 \text{ Hz}) \\ &= 348 \text{ m/s} \\ &= 3.5 \times 10^2 \text{ m/s} \end{aligned}$$

Calculation of Percent Error:

experimental value = 348 m/s
theoretical value = 343 m/s

$$\text{percent error} = \frac{|\text{experimental value} - \text{theoretical value}|}{\text{theoretical value}} \times 100\%$$

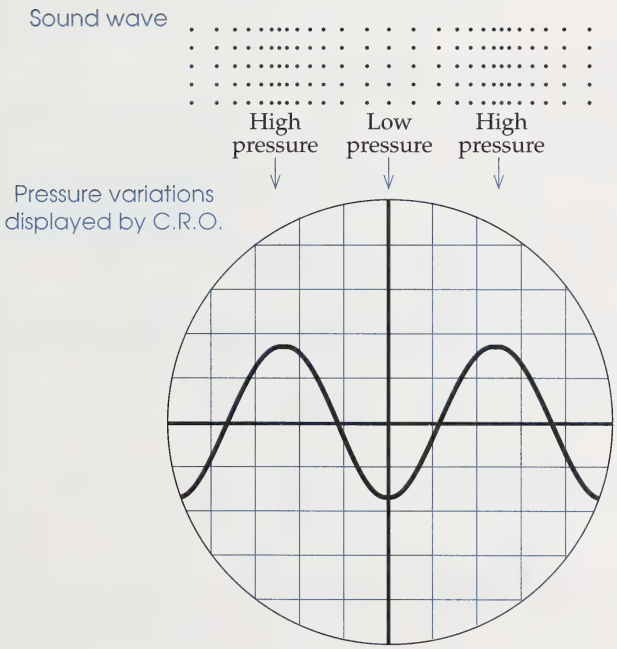
$$= \frac{|348\ \text{m/s} - 343\ \text{m/s}|}{343\ \text{m/s}} \times 100\%$$

$$= 1.46\%$$

$$= 1.5\%$$

Errors in this experiment are usually due to errors in measuring the length of the tube. If the air within the tube was at a temperature other than 20°C, the speed of sound would not be 343 m/s and this could contribute to errors as well. A bucket full of cold water would lower the temperature of the air in the tube and change the results.

12.



13.

	Lowest A	A	A	Highest A
Frequency (Hz)	110	220	440	880

1 octave 1 octave 1 octave

14. This question is answered on the previous chart.

15.

16. Ten flutes would have to be played.

17. Workers wear protective ear muffs to shield their ears from loud sounds.

18. a.
The sound was created by a violin. The sound can be described as being full.

b.
This sound was created by a flute. This sound is pure.

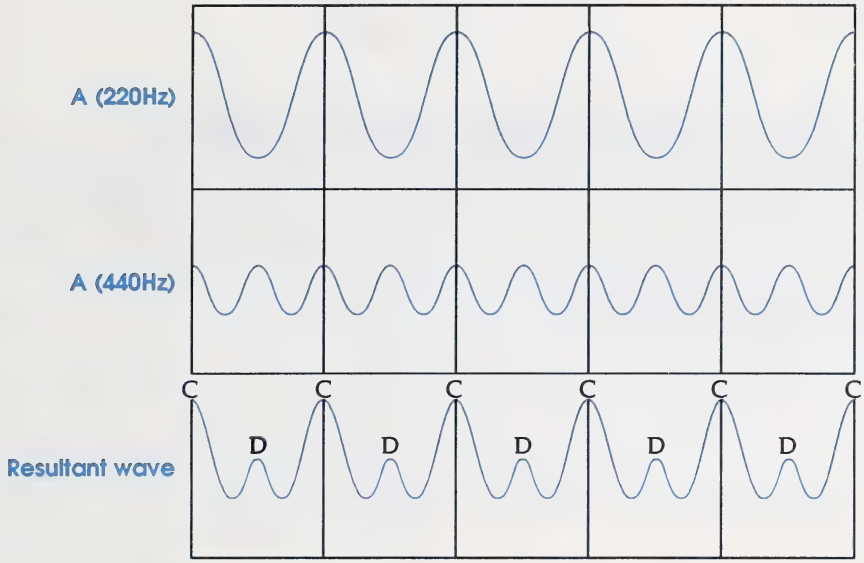
c.
This sound was created by a bassoon. The sound is rich and warm.

d.
This sound was created by an organ. This sound is clear.

e.
This sound was created by Rachel's voice. This sound is pure.

19. a. This question is answered on the chart.

b. This question is answered on the chart.



c. The quality of the sound became more rich and full.

20. a. primary vibrator: lips of player
resonant vibrator: air in tube

b. primary vibrator: reed
resonant vibrator: air in tube

c. primary vibrator: eddies from air jet
resonant vibrator: air in tube

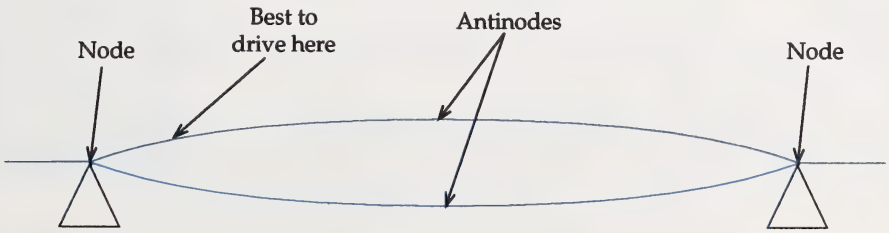
d. primary vibrator: eddies from air jet
resonant vibrator: air in tube

e. primary vibrator: hairs of bow and strings
resonant vibrator: body of violin and air inside sound box

f. primary vibrator: strings
resonant vibrator: body of guitar and air inside it

g. primary vibrator: wooden slats
resonant vibrator: air in tubes

21.



22. A drum head can vibrate in many different ways because it is two-dimensional. Hitting it far from the centre encourages more of these vibrations.

23. An octave is the separation of two musical notes whose frequencies are in the ratio of 2:1. A note of 110 Hz is one octave below a 220 Hz note, while a 440 Hz note is one octave higher.

24. a. vocal cords
    b. lips of musician
    c. lips of musician
    d. reed
    e. reed
    f. eddies in air jet
    g. eddies in air jet
    h. strings
    i. strings

25.

Type of Ear Protection	Reduction in Sound Level (dB)
Cotton Ear Plugs	−10 dB
Special Ear Inserts	−25 dB
Specially Designed Ear Muffs	−45 dB

26. Beats occur due to the superposition of two very similar frequencies. When the waves cause destructive interference, the sound level drops, while the constructive interference creates a louder sound. The result is a pulsing sound that alternates between the constructive and destructive interference.

27. If an instrument is slightly out of tune, beats will be heard when a reference tone is sounded. As the instrument is tuned, the beats become farther apart until the beats finally disappear.

28. Consonance is a pleasing combination of sounds. Dissonance is an unpleasant combination of sounds.

29. Textbook question 2.2. a.:

    The sound comes from the resonant vibrations of the desktop.

    Textbook question 2.2. b.:

    The loudness drops because the towel absorbs the vibrations before they excite the desktop.

    Textbook question 2.2. c.:

    The ruler is like the strings and the desktop is like the body of the guitar and the air inside it.

    Textbook question 2.3.:

    When a person has a cold, the airways become blocked, preventing the sounds from resonating in the usual way.

30. The following list represents the most important equations from Module 5.

$T = \frac{1}{f}$

$v = \lambda f$

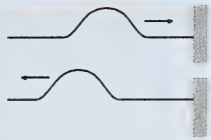
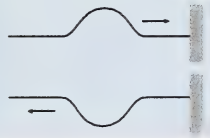
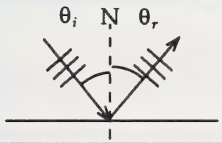
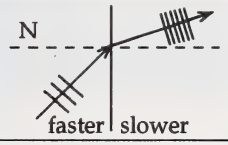
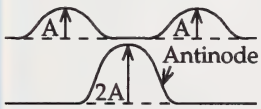
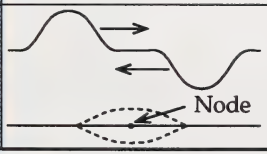
$\frac{1}{2}\lambda = l$ for an open pipe resonator

$\frac{1}{4}\lambda = l$ for a closed pipe resonator

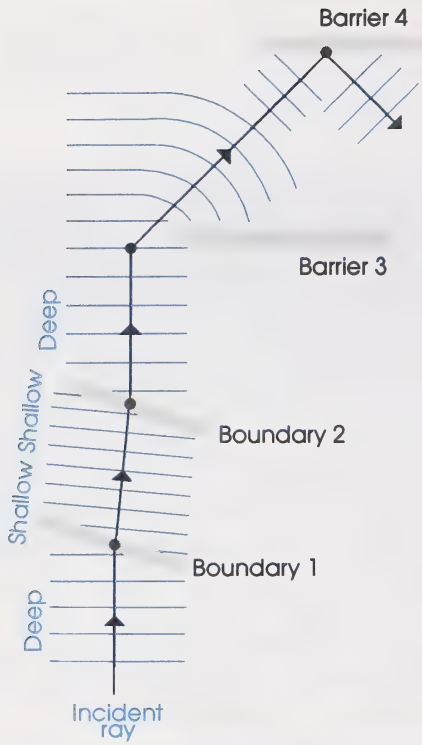
Section 2: Follow-up Activities

Extra Help

1.

Wave Property	Diagram to Illustrate This Wave Property	Point Form Explanation of Main Ideas	Note Any Changes in λ, f, v or A
Reflection from the Boundary of a More Dense Medium		The reflected wave is inverted.	The only variable to change is the amplitude, which is slightly smaller and inverted.
Reflection from the Boundary of a Less Dense Medium		The reflected wave is right side up.	The only variable to change in the amplitude, which is slightly smaller.
Reflection in Two Dimensions		The angle of incidence equals the angle of reflection.	The only variable to change is the amplitude, which may become slightly smaller.
Refraction for a Wave Entering a Slower Medium		The waves bunch up and bend towards the normal.	The frequency stays the same, but both the λ and v are smaller. Since some reflection occurs, the amplitude is also slightly smaller.
Superposition of Identical Crests		The amplitudes add to make a larger crest. This is constructive interference.	The only variable to change is the amplitude.
Superposition of an Equal-sized Crest and Trough		The waves cancel out, creating a node. This is destructive interference.	The amplitude changes as shown.

2. a.



b.

Boundary or Barrier	Property	Description	Changes in Variables
1	refraction (fast to slow)	This is caused by a change in speed. The wave bends toward the normal.	v decreases f same λ decreases $\theta_{deep} > \theta_{shallow}$
2	refraction (slow to fast)	This is caused by a change in speed. The wave bends away from the normal.	v increases f same λ increases $\theta_{deep} > \theta_{shallow}$
3	diffraction	waves spreading around a corner	v same f same λ same
4	reflection	$\theta_i = \theta_r$ incident reflected	v same f same λ same

3. a. $f_1 = 264\ \text{Hz}$
$\lambda_1 = ?$
$l = ?$
$v = 343\ \text{m/s}$

$$v = \lambda_1 f_1$$
$$\lambda_1 = \frac{v}{f_1}$$
$$= \frac{343\ \text{m/s}}{264\ \text{Hz}}$$
$$= 1.30\ \text{m}$$

$\frac{1}{2}\lambda_1 = l$ for open pipes

$$l = \frac{1}{2}(1.30\ \text{m})$$
$$= 0.650\ \text{m}$$

b. The primary vibrator is the jet of air which is cut into eddies at the mouthpiece. The resonant vibrator is the air inside the tube.

c. Leaving this finger hole open makes the effective length of the tube shorter. This means that the fundamental wavelength is shorter and the fundamental frequency is higher.

Enrichment

1. Superposition is applied in the cancellation of sound by sending waves to destructively interfere with the unwanted noise. It works best with low frequency and long wavelength noise. The long wavelength is easier to hit with antinoise sound. These are also the noises that cause the most fatigue.

   Sound beams could be removed if the whine of the tires was eliminated by antinoise at the source (the vehicle).

   Applications include reducing the noise in the following items:

   - headsets for pilots
   - vacuums and other electric fan-type appliances
   - magnetic resonance imaging
   - lawn mowers
   - hair dryers
   - shipping yards
   - diesel systems
   - air conditioning ducts
   - vehicles
     - muffler systems
     - unwanted road noise
     - engine resonance

   The safety concern is that you don't want to create a situation where you can't hear anything, including sirens and horns.

2. a. The shortest length will give the highest sound. This matches with what you discovered for open tube resonance in which the length of tube determines how many wavelengths will occur within that tube.

   b. The suspended tube will produce a clear ringing sound. The quality of a musical note depends on the number and intensity of the overtones or harmonics which accompany the basic note. A length of tube will produce a number of different vibrations and overtones when struck.

3. Answers to this activity can be found in the Critical Thinking package.

4. Suggested answers to this activity can be found in the teacher's edition of the laboratory manual.

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Physics 20

Student Module Booklet

Module 5

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